AGRICULTURAL PRACTICES AND NITRATE POLLUTION IN GROUND WATER IN THE CENTRAL VALLEY OF CHILE

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ABSTRACT

Nitrate contamination of groundwater is an issue of global concern. Anthropogenic fixation of nitrate has increased exponentially in the last century and the over-application of nitrogen fertilizer is currently the largest intrusion into the nitrogen cycle. Previous studies have determined that various regional conditions can contribute to the level of nitrate contamination in groundwater. In addition to chemical and physical conditions, fertilizer application rates and over-irrigation can serve as compounding factors. This study attempted to analyze the previously mentioned conditions by monitoring nitrogen concentrations in ground water from sampling wells in the Central Valley of Chile over a 13-month period. Samples were collected monthly and nutrient concentrations were analyzed. In all wells, concentrations of nitrate and nitrite were determined to be well above the established MCL's for each and a general trend was observed in the concentrations that correlates to seasonal changes in land-use practices. A field experiment was conducted to reduce fertilizer application rates and irrigation water volumes applied to test fields by deploying an experimental fertilizer/ irrigation system. Data from the sampling wells associated with the test fields shows a substantial decrease in nitrate and nitrite concentrations in the ground-water. Furthermore, when the experimental system was combined with improved water delivery methods (medium-volume furrow flooding and low-volume drip irrigation) a decrease in water volumes and fertilizer application rates of up to two– thirds was obtained without affecting crop yield rates. Results of this study suggest that the over-application of fertilizer and irrigation water reported in previous studies are in fact areas of concern and that a link exists between ground-

water recharge and irrigation volumes. It is further suggested that long-term application of the experimental system is necessary to prove its benefits to the agricultural, ecological, economical, and scientific communities. If the performance record for this device can be repeated under a variety of conditions its role in reducing global intrusions to the nitrogen cycle would be substantial.

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DEDICATION

I would like to dedicate this thesis to three of our team's finest members: Sgt. John Chapman, Senior Airman Jason Cunningham, and Sgt. Philip Svitak. All three men were killed in action approximately 70 miles south of Kabul, Afghanistan in March of 2002. "These Things We Do That Others May Live". God Speed.

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INTRODUCTION

Regional History, The Development and Importance of Irrigation in the Study Area

The Central Valley of Chile is well known for its agricultural productivity. This region is responsible for producing 83 percent of the Chile's agricultural export and 96 percent of the domestic agricultural crop. A tour of the Central Valley yields countless vineyards, commercial farming operations, and thousands of family farms. As fruitful as the Central Valley is, it was not always this way. The productivity of this region is as much a historical tale as it is one of agronomy. The fertility of the Central Valley is an illusion made possible by a single factor- the life-giving river systems and their annual cycle of drought and recharge.

Irrigation is key to agricultural success in the Central Valley and to the national economy as a whole. Three of the top ten economic contributors are multi-national agro-firms based in this region. Despite the importance of the region to the entire nation, very little effort has focused on protecting the natural resources of the area (SESMA, 1999).

In the Central Valley water is viewed as another form of currency and in many instances it is traded for the peso at a hyper-inflated rate. Although the topic of this thesis is the contamination of ground water due to agricultural practices, it is a disservice to discuss nitrate contamination without exploring the history of regional agriculture that is responsible for shaping local views of land and water use.

The area of the Central Valley chosen for this study lies in the vicinity of the Tinguiririca and the East Antivero River systems. Both of these rivers are responsible for providing irrigation water to the area and play an important role in regional hydrodynamics and agroeconomics.

The Tinguiririca River runs its full course between 34 and 35 degrees south latitude. It is a river system that is unique for many parts of the world but average for the central region of Chile. With a drainage basin of over 10,000 square kilometers it is larger than many of the rivers in the region yet the physical, chemical, geological, and biological features are fairly standard for a river of this type. The East Antivero is a much smaller system and of greater importance further downstream, outside of the study area (Nano, 2001).

The land surrounding the watershed was originally divided into family plots by the colonial government in Santiago. Each plot consisted of slightly over 600 acres and was given to families who were active in the colonial government (Briones, 2000). A single stipulation was applied to this grant by the government; the land must be used for agricultural purposes in an attempt to feed the country's growing population. Early agricultural development in the region was made possible by utilizing and improving upon a system of irrigation that the Spaniards witnessed further north in Ecuador and Peru. This system of canals proved successful in central Chile and many of the original systems are still in use today.

With the success of irrigation, the Central Valley was transformed from semi-arid savanna to fertile, green cropland. This transformation occurred in a very short period of time and became the first major ecological disturbance in the region. Water was being removed from the main river channel, diverted, and in many cases ending up on agricultural fields through the process of flood irrigation. A natural system that was in place for at least 40 million years finally met a tough contender- humankind.

The success of this method of channeling water to increase productivity led to the issuance of more land grants for the region. By 1783 the watershed was further divided and a total of 21 large plots were now in existence. All of these *fundos* (large family farms ruled by a Don or landowner) were now relying on the Tinguiririca for irrigation water. Municipal records show that the population of each fundo reached at least 700 people by 1795. With 21 fundos in existence, the population of the valley was now well over 14,000 inhabitants (Municipalidad de Nancagua Archive).

To completely understand the impact that agricultural growth had on the river it is necessary to look at each individual fundo as a separate community. Each of these large family farms were cities within themselves. The "city" within the fundo drew drinking water from shallow wells along the river, irrigation water from the main channel, and disposed of their sewage directly into the river through a similar system of canals as those used for irrigation. In the span of just under fifty years a remarkable transformation had occurred in the Tinguiririca valley. In 1801 it was reported that the river fell short of reaching the coast (Archive of San Fernando). The increased demand for irrigation water had finally taken its toll and cut short the natural system. Although the highly organized, communal system of the fundo is no longer in place, regional water distribution is controlled by a similar organization. In recent times the irrigation collective or cooperative organization has taken over the maintenance of these systems and controls water-usage allowances.

The Central Valley Today

Today the population around the Tinguiririca river valley is well over 230,000 inhabitants. Government reports for the region state that about 190,000 of those people work in agriculture or agro-business (Castillio, 2001). The climate in this area is ideal for agriculture. Because farmers have an unlimited amount of water for most of the year, crop rotation occurs on a much faster basis, thus allowing for two separate harvests. Furthermore a localized climate allows for the production of both temperate and Mediterranean crops. The value of this region is internationally understood and there are currently over twenty international agribusinesses in place.

Over the past two hundred years the river has fallen short of reaching the next branch in its continuum at least sixty times (Archive of San Fernando). The summer season of 2001 was one of those times (personal observation). These conditions have been explained to illustrate the volume of agricultural irrigation that occurs within the study region. Studies conducted in areas with similar climatic conditions have shown that the rate of irrigation directly corresponds to the rate of ground water recharge (Bonilla et al., 1999). Unfortunately there has been very little in the way of regional studies reported in published literature; and the modeling studies made have been on a much larger scale, between the III and VIII regions (Donoso et al., 1999).

The below average rainfall for the region coupled with highly volume irrigation practices and massive applications of industrial fertilizers make ground water contamination seem inevitable. Additionally the sandy soil of the region increases the likelihood of ground water contamination. Studies have shown that the rate and occurrence of nitrogen leaching depends on underlying soil and / or parent bedrock conditions (Killpack and Buchholz, 2001). Finally the shallow depth of the regional water table and the socio-economic conditions that prevent the construction of deep-pulling wells are compounding factors, all of which contribute to the possibility of ground water contamination.

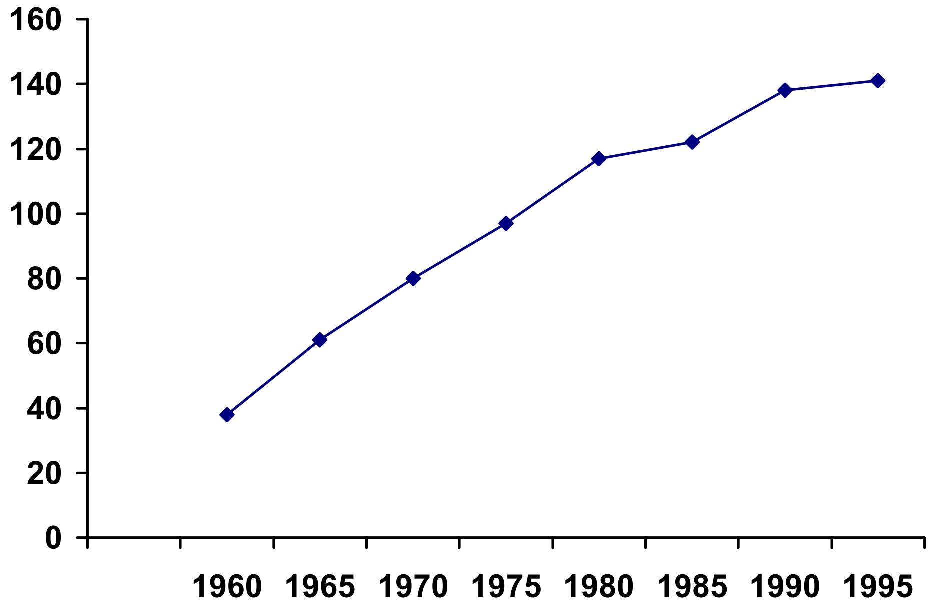
In recent years the municipal government has made a large-scale effort to develop water delivery systems for residential use. Although potable water is available to a large number of people in the Central Valley's agricultural plain, many still consider it a luxury and rely on pozos (shallow wells) for their daily water needs. Many of the wells that have not been designated as drinking water wells are still used by laborers and farmhands (Briones, 2000).

The Agricultural Application of Nitrogen Fertilizer

Since the 1940's, human alteration of the global nitrogen cycle has been substantial compared to any other time in human history. Fertilizer use has increased exponentially since the post-World War II years and over one-half of all fertilizer produced has been applied since 1984 (Vitousek et al., 2001) (Figure 1). There are several factors that have propelled this growth in the agrochemical industry, but none more important than the production of synthetic nitrogen fertilizers and chemical pesticides. Both products have allowed regions with naturally low soil fertility to be developed as productive areas of agricultural importance. Synthetic nitrogen fertilizers were born from the efforts of Haber and Bosch in 1899, but proved to be too expensive to produce on a large scale until the demand rose for nitrogen-based explosives during the Second World War (Smil, 1997).

In the 1960's, developed nations accounted for more than 90 percent of synthetic fertilizer consumption, but by 1980 that rate had decreased to below 70 percent. Developing nations now consume more than 63 percent of the nitrogen fertilizer produced globally (Vitousek et al., 2001). In recent years there have been major efforts to transform unstable, hunter-gatherer societies into stable, agricultural communities.

Figure 1. Global Trends in Anthropogenic Nitrogen Intrusions from 1960 to 1997. Data shown in million metric tons of nitrogen or teragrams (Tg)



Source: Vitousek, et al., 2001.

The Shone people of Africa are a great example of these efforts. In the process of transformation a small amount of land is used to support a growing population. In many cases this scenario is representative of the changes that occurred during the agricultural revolution. During this modern transformation, human population growth is not subject to the ecological pressures that were present 12,000 years ago; instead unfertile land can be augmented and manipulated with the use of fertilizers.

Human control of soil fertility would not be possible on such a large scale without the industrial production of nitrogen fertilizers. Smil (1997) emphasizes this importance- "Yet the statement that one third of the protein nourishing humankind depends on synthetic fertilizer also underestimates the importance of these chemicals. A number of land-scarce countries with high population density depend on synthetic fertilizer for their very existence. As they exhaust new areas to cultivate, and as traditional agricultural practices reach their limits, people in these countries must turn to ever greater applications of nitrogen fertilizer".

Currently over one-third of the earth's land surfaces are devoted to agriculture and it is estimated that more than 90 percent of that land relies heavily on commercial fertilizer application (Smil, 1997). Synthetic fertilizers provide about 40 percent of all nitrogen applied to agricultural crops (Hallburg, 1986). Over 80 teragrams of nitrogen fertilizers are applied globally each year. [A teragram, abbreviated as Tg, is equal to a million metric tons]. Using recent rates of increase, various sources have estimated that nitrogen fertilizer application will exceed 134 Tg per year by 2020 (WRI 1999). Human activities now contribute more to the global supply of fixed nitrogen than natural nitrogen fixation. Human-generated nitrogen currently contributes slightly over 210 Tg per year while natural processes account for only 140 Tg. It is important to note however that this human intrusion into the global nitrogen cycle is more complex than the application of fertilizers for agriculture. Activities such as the burning of fossil fuels also play a part in adding excessive nitrogen to the environment (Table 1).

The problem with nitrogen fertilizer lies not in application but in over-application. Comparatively low cost coupled with a demand for high crop yields often encourages overuse. Conservative estimates show that between two-thirds to one-half of every metric ton of fertilizer applied is never incorporated into plant tissue (Vroomen and Taylor, 1992). The wasted nutrients in the excess fertilizer may react with other chemicals in the soil and undergo change, evaporate into the atmosphere, or become subject to microbial activity. Regardless of the fate of the excess nutrient, it is evident that human alteration of the nitrogen cycle is an issue of major global proportions.

Fertilizer Use Within the Study Region

There are a number of nitrogen inputs into agricultural fields. In most agricultural regions, a combination of synthetic fertilizer and animal manures used as fertilizer are major inputs. In the region examined in this study, most fertilizer application is of the industrial-chemical variety. There is very little application of animal manures or green-fertilizers, with the exception of small-scale subsistence operations and postseason composting of remaining crop material. A timeline of major agricultural practices within the study region is displayed in Table 2.

While the majority of fertilizer applied within the region is used on corn and tobacco fields, there are numerous other crops that are highly fertilized. The variety of agricultural products grown in the Central Valley is tremendous and there are many unknowns concerning fertilizer application at this time. However, it is important to note

Table 1. Global Sources of Fixed Nitrogen
Data shown in million metric tons of nitrogen or teragrams (Tg)

ANTHROPOGENIC SOURCES	**ANNUAL RELEASE OF FIXED NITROGEN**
Fertilizer	80
Legumes and other plants	40
Biomass burning	40
Fossil fuel burning	20
Land clearing	20
Wetland clearing	10
Total from anthropogenic sources	**210**
NATURAL SOURCES	
Soil and symbiotic bacteria, algae, and lightning	140

Source: World Resource Institute, *Global Trends* 1999.

Table 2. General Agricultural Timeline for the Study Region

STUDY MONTH	AGRICULTURAL ACTIVITY
1 FEBRUARY	CROP HARVEST IN MOST OF THE STUDY FIELDS LATE IN THE MONTH, REMAINING CROP MATTER MAY BE PLOWED INTO GROUND AS GREEN MANURE
2 MARCH	CROP HARVEST DEPENDING ON ALTITUDE, IRRIGATION, FERTILIZATION REGIME, AND CROP TYPE
3 APRIL	ABSENCE OF IRRIGATION AND FERTILIZATIONMOST FIELDS ARE NOT UTILIZED
4 MAY	SAME AS MONTH 3
5 JUNE	SAME AS MONTH 3
6 JULY	PLANTS ARE STARTED IN SEED BEDS NOT IN FIELDS
7 AUGUEST	SAME AS MONTH 6
8 SEPTEMBER	SPINDLINGS (IMMATURE PLANTS) CONTINUE TO DEVELOP
9 OCTOBER	PRESEASON FERTILIZER APPLICATION, FIELDS WHICH ARE USED FOR A DOUBLE HARVEST MAY BE PLANTED IN THE 1ST WEEK OF THIS MONTH, IRRIGATION BEGINS IN THESE FIELDS
10 NOVEMBER	REMAINING SPINDLINGS ARE TRANSFERRED TO FIELD, FERTILIZATION AND IRRIGATION CONTINUE
11 DECEMBER	CROP DEVELOPMENT, CONTINUED IRRIGATION AND FERTILIZATION PRACTICES ARE DICTATED AND ADJUSTED BY THE EXPECTED CROP YIELD RATES (THESE RATES ARE DETERMINED BY FIELD PERSONNEL)
12 JANUARY	SAME AS MONTH 11
13 FEBRUARY	SAME AS MONTH 1

that many fruits and vegetables grown in the region have a much higher fertilizer application rate than that of corn or tobacco. As either of the two above-mentioned crops are rotated out of a particular area, the field may be used for more heavily fertilized fruits or vegetables (Table 3).

A more traditional approach of replenishing soil fertility has been to plant soybeans or other leguminous crops once the nitrogen-robbers have been rotated out (Peterson and Russells, 1991). However, with an increased emphasis on production, nature's way of replenishing soil fertility often fails to keep pace with the human timeline. In recent years, the fertilization of nitrogen fixing crops has also increased. In the US alone, the application of nitrogen fertilizer on soybeans now exceeds 25 percent for a total of 144 million pounds of fertilizer per year (USDA 1995). Detailed data for soybean and alfalfa fertilization within the study region was unavailable, but a survey of farmers growing either of the two legumes determined that over 30 percent of the farmers applied nitrogen-based fertilizers to these crops.

Fertilizer application in the Central Valley is very similar to that which exists in other areas of equal agricultural importance. The general trend in fertilizer application is that more fertilizer is being applied to the land and in many cases the rate of application exceeds the crops' ability to utilize the nutrient (Rosenfield, 1993); (Peterson and Frye, 1989). The end result is an excessive concentration of nitrogen in the soil, much of which percolates below the root zone and then leaches into the ground water.

Nitrogen fertilizer is used more heavily on corn fields than on any other major agricultural crop. Every cornfield within the study area received nitrogen fertilizer at least two times each season. Any corn field of less than one acre was excluded from this

Table 3. Common Fertilizer Application Rates for Irrigated Crops.

	POUNDS OF FERTILIZER PER ACRE		
CROPTYPE	**N**	**P_2O_5**	**K_2O**
Alfalfa	20	120	50
Barley	120	60	40
Cabbage	220	90	40
Cauliflower	120	60	30
Carrots	120	60	30
Green peppers	60	45	30
Red peppers	80	45	30
Corn (field/ sweet)	200	80	60
Cucumbers	100	80	30
Grapes	60	30	20
Green beans	20	60	30
Pasture grass	200	60	60
Legume grasses	160	75	60
Lettuce	200	100	60
Oats	100	40	25
Onions	200	100	60
Peas	20	60	30
Pinto beans	20	45	25
Irish potatoes	200	180	150

Table 3. (cont.)

Rye	150	90	60
Sorghum grain	50	60	30
Sweet potatoes	160	150	120
Tomatoes	80	80	60
Watermelon	100	45	25
	Fertilizer application for fruit trees is expressed in pounds of nitrogen per inch of trunk diameter		
Apples	¼		
Pears	¼		
Peaches	¼	Application should not exceed 5 pounds per tree	
Plums	¼		
Oranges	¼		
Limes	¼		

survey with the exception of those in close proximity to a study well ($d = 10$ meters or less).

Fertilizer is applied to cornfields at a mean annual rate of 200 pounds per acre. This is much higher than the US rate of 129 pounds per acre in 1995 but aligned with past predictions on current fertilizer use (Woodward, 1995). A large percentage of the land within the study area is devoted to growing tobacco. This crop is considered to have high nitrogen and potassium demands and requires a great deal of fertilization to achieve the desired crop yield. A mean value of 130 pounds per acre of nitrogen fertilizer was calculated based on data collected over four growing seasons by the field agronomists employed by this study.

Nitrogen Fertilizers, The Human Health Impact

There are three forms of nitrogen fertilizers applied to the land: nitrate, ammonium, and urea. Nitrate, in particular, is very soluble in water and easily assimilated into mammalian systems. The most common ailment that has been linked to elevated nitrate concentrations is methemoglobinemia or more commonly known as "Blue Baby Syndrome" (Bruning and Kaneene, 1993). This ailment results from the high pH of the baby's gastro-intestinal tract and the subsequent conditions in which nitrate reducing bacteria proliferate. As a result of these conditions, nitrate is reduced to nitrite, which then oxidizes with the hemoglobin of the red blood cells and methemoglobin is formed. The abundance of methemoglobin in the body leads to an inability of red blood cells to effectively transport oxygen to other body cells. Although this ailment is most common in young children, methemoglobin is produced by everyone but quickly converted back to normal hemoglobin in more than 98 percent of the population.

Although less conclusive, there are published reports that link elevated concentrations of nitrate and nitrite to several types of cancer and teratogenic effects (Cerhan, 2001); (Clough 1983). Lymphatic cancers and stomach cancer have been reported with greater frequency in populations exposed to elevated nitrate concentrations in their drinking water (NCI, 1999). One of the few epidemiological investigations in the region of this study discovered a positive association between stomach cancer mortality and nitrate fertilizer (Zaldivar, 1973). In all of the above cases, the resulting cancers are more a case of the synergistic relationships between the nitrate, bacteria, and other chemicals present in the soil.

A more recent study conducted by Johns Hopkins University examined 385 cases of non-Hodgkin's lymphoma (NHL) over a three-year period in Nebraska. Although there was a correlation between shallow private wells, which are thought to have greater concentrations of nitrate than community water sources, and instances of NHL, there were a number of confounding factors (Ward, 1995).

Nitrate has not been proven or suspected to be a carcinogen; instead it is considered a pro-carcinogen. This means that it can react with other chemicals to form carcinogenic compounds. This usually occurs via a multi-step process, the first of which is the endogenous reduction of nitrate to nitrite (Kalble et al., 1990). Within the body, nitrate reacts with compounds known as secondary amines or amides to form N-Nitroso compounds (either nitrosamines or nitrosamides). These compounds have been associated with at least fifteen different types of cancer including the following: tumors in the bladder, stomach, brain, esophagus, bone, skin, kidney, liver, lung, oral, nasal, trachea, thyroid, pancreas, and peripheral nervous system. Many of the compounds formed through these processes are very similar to those that would be inhaled during cigarette smoking and have similar biochemical consequences (Mirvish, 1991, 1983).

Studies have shown that a diet of nitrate and amine-rich foods can also contribute to the formation of nitrosamines (Westin, 1999). In these studies, those who consume a high nitrate and high amine diet, the later mainly in the form of amine-rich seafood, were at an increased risk of endogenously forming carcinogenic nitrosamines. These studies further stressed the role that bacteria play in nitrate reduction by examining the influence that the use of antibacterial mouthwash had on oral nitrate reduction rates. The authors believe that removing the bacteria from the oral cavity may actually inhibit nitrosamine formation by reducing the rate at which dietary nitrate is reduced to nitrite (Westin, 1999).

The International Agency for Research on Cancer has also independently concluded that at least 11 common N-Nitroso compounds should be avoided (IARC, 1978). Furthermore, of more the than one hundred N-Nitroso compounds tested by the National Academy of Science, more than 75 percent have been found to be carcinogens in laboratory testing (NAS 1977).

An additional concern in areas of agricultural activity is the formation of nitrosamines in the soil under certain conditions. A number of agricultural chemicals, mainly in the form of pesticides, contain chemical structures that can be biodegraded into secondary amines. Nitrosamines have been shown to form in the soil when these secondary amines and elevated nitrite concentrations are present in acidic soil conditions (Mallik, et al., 1981). These compounds then enter the food chain through their incorporation into plant tissue and the subsequent consumption by heterotrophs. The data from the Mallik studies suggests that the presence of organic matter in the soil is a contributing factor to the rate at which secondary amines accumulate. Based on this data areas with a low organic soil component should have an increased rate of secondary amine formation. Pancholy, Mallik, Ayanaba and Alexander have all shown that the nitrosation reaction is heavily influenced by the presence of a physical, organic soil component. In these studies the organic soil component has been defined qualitatively rather than quantitatively, such as measuring the concentration of organic carbon present.

Aside from the above-mentioned research calling for the reduction of nitrate in drinking water and dietary intake, there are recent studies that support a certain level of nitrate consumption. A 1997 study reported the importance of dietary nitrate intake through the consumption of high-nitrate vegetables. These studies have shown that oral nitrate reduction actually supports an important resistance mechanism against infectious disease in mammals. The study also states that the conversion of nitrate into oxides of nitrogen may actually prevent the formation of nitrosamines (Callum et al., 1997).

Another study proposed that the skin's production of nitric oxide and the subsequent bacterial nitrate reduction on the surface of the skin may actually be a factor in promoting skin health (Weller et al., 1996). The authors have proposed that the further reduction of nitrite by acidification may inhibit the infection of pathogenic fungi, affect cutaneous T-cell function, and promote healthy blood flow in the skin.

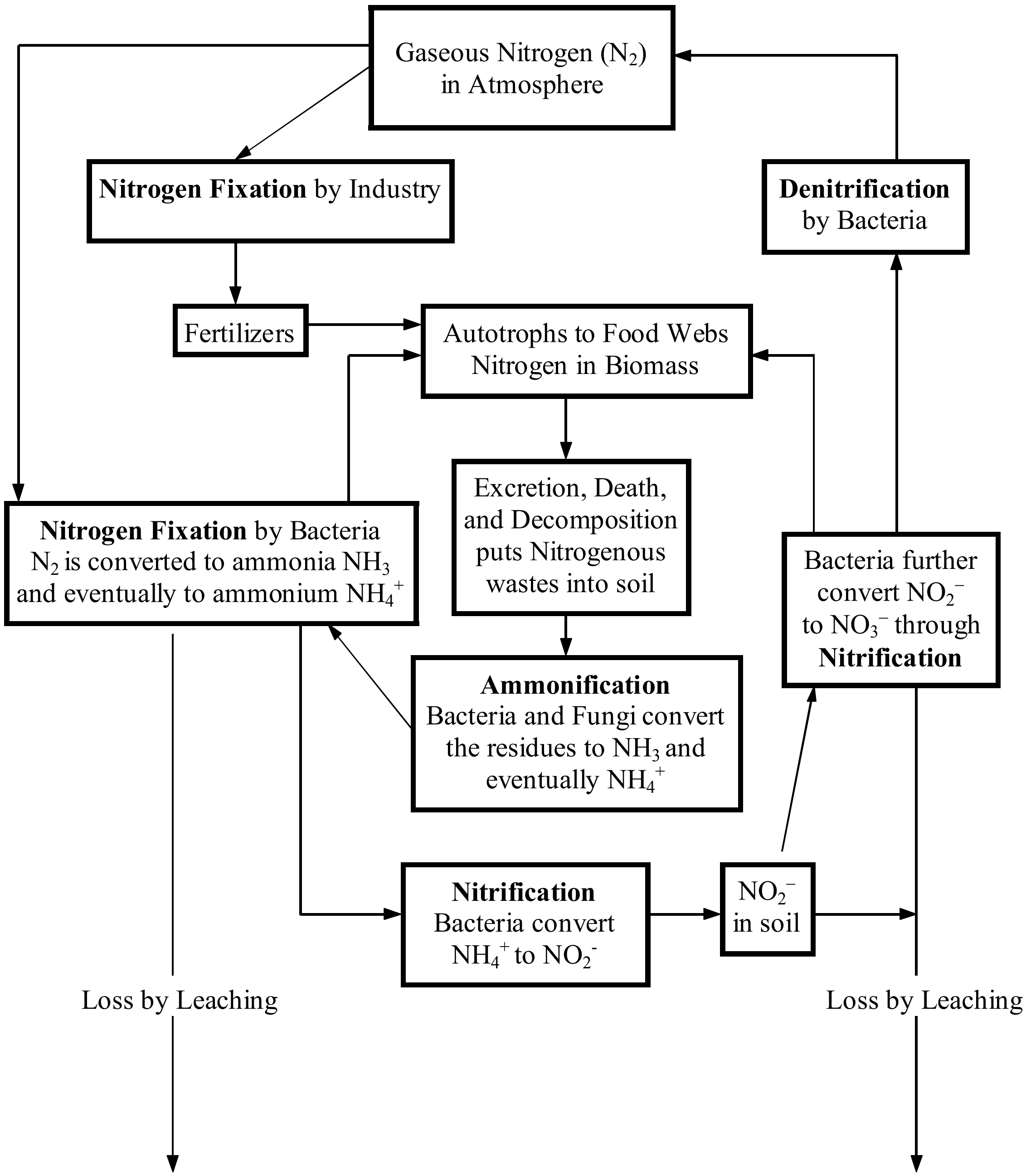
A large number of studies have investigated the role of excessive nitrate intake in human health. All of these studies have reported negative effects but there seems to be a general lack of communication between the researchers and public/ environmental health officials. The currently used MCL for nitrate in drinking water is 10 ppm. This limit is based on a 1945 study and some argue that it is too high. Only two nations, Germany and South Africa, have lower recommended consumption levels. There seems to be data available to support a reduction of the MCL but in many cases the data or actual experimental design has been criticized (Fan, 1987).

Nitrogen Fertilizers, The Ecological Impact

Nitrogen is an element of great importance to all living things. It is needed to make proteins, build tissue, and even a necessary component of DNA. Although nitrogen gas (N_2) accounts for approximately 78 percent of the Earth's atmosphere, it cannot be directly absorbed by most organisms. Instead, most of the biotic realm must rely on nitrogen-fixing organisms to convert atmospheric nitrogen to a usable form. Soil-borne bacteria or symbiotic bacteria living in specialized root structures in leguminous plants accomplish the terrestrial fixation of nitrogen, converting N_2 to NH_4^+. A small amount of atmospheric nitrogen is also fixed by lightning. It has been estimated that lightning is responsible for fixing less than 10 Tg of nitrogen per year.

The amount of atmospheric nitrogen being fixed at any given time is small when compared to the pool of fixed nitrogen that exists in living organisms and decaying organic matter. Much of this fixed nitrogen exists in a biological reservoir, tied up in the structural proteins and organic molecules of plants and animals. Once incorporated into living tissue, the fixed nitrogen moves through the biotic realm much like carbon cycling through a food web. The nitrogen that is not incorporated into new biomass leaves the organism through the expulsion of waste products and becomes available to primary producers once again as the detritial component of soil or dissolved in aquatic systems (Boyd, 2001). The nitrogen cycle relies heavily on microorganisms and it is considered to be one of the most complex of all biogeochemical cycles (Figure 2).

Figure 2. The Nitrogen Cycle



Source: Starr and Taggart, 2001.

Since the development of industrial nitrate fixation, human activity has doubled the amount of nitrogen biologically available (Vitousek et al., 2001). Perhaps the most noticeable regional disturbances occur in areas where agriculture occupies the majority of developed land. In many cases these areas have ground water nitrate concentrations well above the accepted MCL (Stites and Kraft, 2001); (Puckett, 1994); (Keeny, 1989).

In terrestrial ecosystems, excessive fixed nitrogen can contribute to a lack of biodiversity and the loss of long-term soil fertility (Smil, 1997). Ecological studies have shown that in areas where nitrogen fertilizer was applied in excess, various grasses were able to dominate and floral biodiversity decreased (Bin-le, et al. 2000). In agricultural areas, nitrogen saturation can lead to disruptions in soil chemistry. Studies have shown that soils subjected to prolonged agricultural use are often lacking in soil micronutrients such as calcium, magnesium, and potassium. Excessive fertilization increases the primary productivity of the land but fails to return micronutrients to the soil (Brown and Johnson, 2001). The data from these studies suggests the idea that the generous use of nitrogen fertilizers may be a shot-term solution to feeding the world's increasing population (Hadas, et al., 1999).

The hydrosphere is also under the influence of these nitrogen intrusions. Nutrient pollution is often the result of non-point runoff and originates from three major sources: commercial feed lots and animal operations, human sewage, and agricultural fertilizer use. In general, the accepted rule is that whatever is applied to the ground eventually makes it into the water (Hallburg, 1989).

Freshwater eutrophication is amongst the most obvious consequences of nutrient pollution. Eutrophication is a natural process by which an aquatic ecosystem becomes more productive and nutrient rich as it ages. However, unnatural levels of nutrients resulting from human activity accelerates the process, known as cultural eutrophication. The mechanism for change is quite simple and occurs in an orderly progression of events. Excess nutrient input acts as a fertilizer and increases photosynthetic activity; this leads to an initial increase in dissolved oxygen levels and an increase in the system's carrying capacity. Once the excess plant biomass dies, decomposition occurs and the populations of decomposing, oxygen-consuming bacteria increase. The net result is a reduction in the dissolved oxygen in the system and a subsequent reduction in the system's biodiversity.

Problems resulting from increased nitrogen loading in aquatic systems are not restricted to farm ponds or agricultural feedlots. Some coastal rivers in the northeastern United States and Europe are receiving more than 20 times the natural amount of nitrogen (WRI, 1999). Nitrate levels in many northern European and Canadian lakes have doubled in just over eight years (Vitousek et al., 1997). The general rule can now further be extended to state that whatever is put on the ground may eventually make its way to the ocean (Phipps, 1997). The end result of nutrient loading is a lack of ecological stability in coastal estuaries and inshore waters. In some cases this instability may reach further offshore. The existence of ocean "dead zones" or areas of diminished productivity is now widely documented. Perhaps the most notable of these zones originates at the mouth of the Mississippi River and extends outward into the Gulf of Mexico (Pew Commission Report, 2003).

Some studies have linked excessive nutrient pollution with the occurrence of harmful algal blooms, otherwise known as HABs (Anderson, 1998). A USGS report from 1998 tries to connect outbreaks of *Pfiesteria*-like organisms with high nutrient levels. The report states "Scientists suspect a link between high nutrient levels in water and the occurrence of algal blooms and the occurrence of *Pfiesteria*-like organisms" (Phipps, 1997). USGS studies show that as much as 50 percent of the water in streams comes from ground water but that this figure can be as low as 27 percent or as high as 85 percent depending on the depth of the regional water table. The report concludes that up to one-half of the nitrogen entering the Chesapeake Bay travels through ground water. This same method of transport may be responsible for as much as 20 percent of the phosphorus entering the bay. Finally, travel time for ground water within the Chesapeake watershed is within a range of 1 to 60 years with an average travel time of 15 years (Phipps, 1997). This study further supports the theory that ground water pollution eventually has an impact on marine systems.

METHODS AND MATERIALS

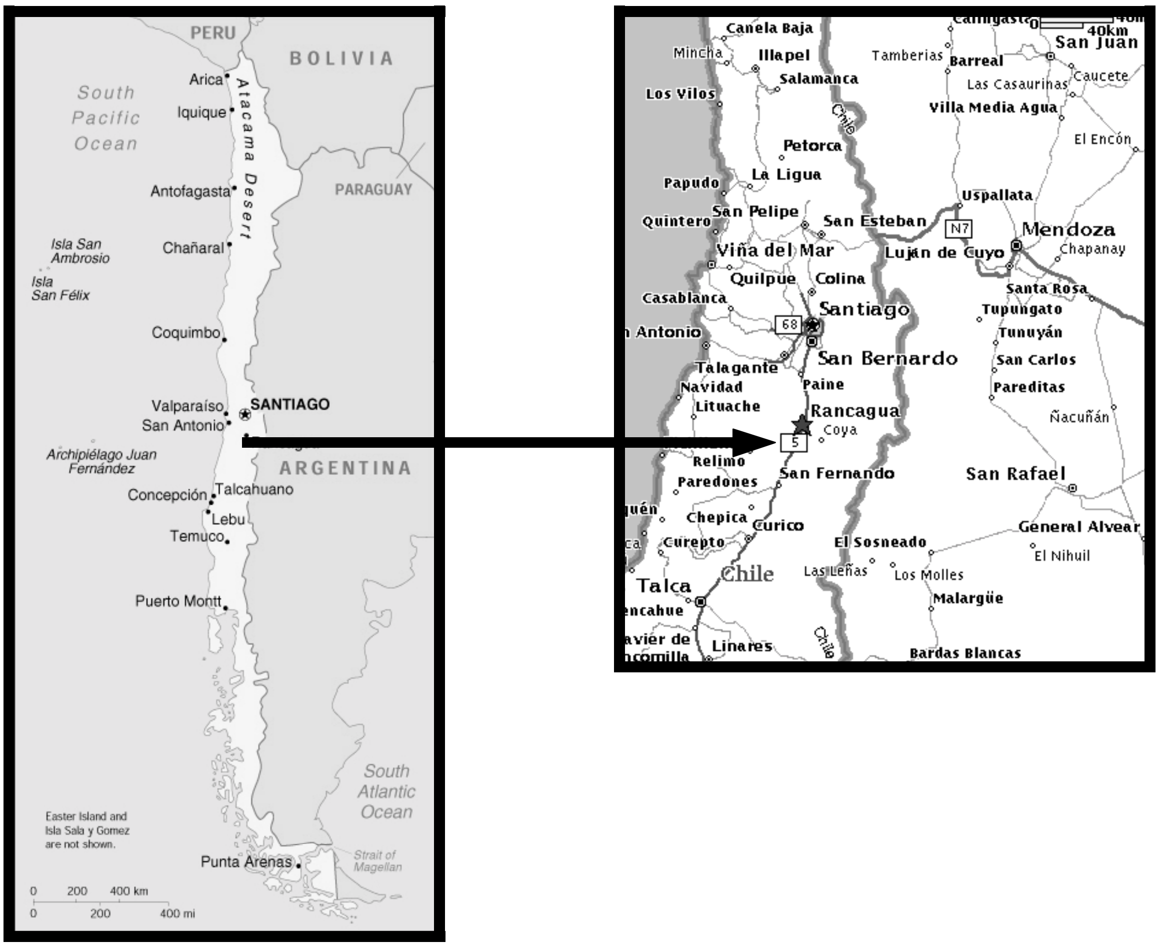
This study monitored nitrate concentrations in shallow drinking water wells in the Central Valley of Chile in an attempt to identify correlations between those concentrations, the amount of nitrogen fertilizers applied, and irrigation practices in the region. A goal of this study was to develop best management practices for irrigation and fertilization techniques.

Beginning in February of 2001, 17 wells were selected and sampled in an area around San Fernando, Chile (Table 4). San Fernando is located 140 kilometers south of Santiago and in the sixth region of Chile (Figure 3). It has a population of slightly over 64,000 inhabitants and lies in the heart of the Central Valley. The study wells selected represent the rural, drinking water wells in the region and are in close proximity to

Table 4. Location of Sample Wells.

SAMPLE WELL	ELEVATION feet above sea level	S. LATITUDE degrees, min, sec	W. LONGITUDE degrees, min, sec
A	833	34 38 21	71 03 55
B	887	34 38 21	71 04 16
C	779	34 38 33	71 07 45
D	710	34 39 29	71 13 17
E	680	34 38 54	71 11 51
F	712	34 39 59	71 11 22
G	688	34 40 19	71 12 06
H	694	34 40 22	71 12 05
I	662	34 39 59	71 14 12
J	666	34 40 06	71 15 07
K	544	34 38 25	71 17 02
L	552	34 40 38	71 18 33
M	553	34 40 38	71 18 40
N	544	34 35 32	71 27 09
O	419	34 31 04	71 22 39
P	441	34 31 03	71 21 51
Q	604	34 37 29	70 56 03

Figure 3. Location of Study Region



agricultural fields (Figure 4). Water samples were also collected from several deeper drawing wells for comparison. The 17 wells chosen were functional throughout the study period and were used by a great number of people. The potential human health impact from degraded water quality in the study wells is substantial because numerous families and countless field laborers use them for drinking water.

All of the study wells are located within the Tinguiririca and East Antivero River systems. They are all closely associated with agricultural areas and none of the wells are within 200 meters of an impervious surface (e.g. paved road). A survey of the land within the study area found that over 84 percent of the land is used for agricultural purposes, much of which are large-scale commercial farming ventures. Residential land use accounts for an additional 12 percent and agro-industry the remaining 4 percent (Figure 5). These percentages are similar to those for the lower watershed of both rivers.

The Central Valley rarely gets any accumulation of precipitation throughout the year. The summer season is hot and dry while the winter season is cool and dry. Instead of direct recharge through the percolation of precipitation, the ground water system is replenished by the spring and summer thaw of snow accumulation from higher elevations. The seasonal accumulation of snow in the Central Cordillera (the Andes) can be in excess of 5 meters. Seasonal thaw of this volume of snow is a prolonged event and will last throughout the entire summer. As a result, ground water levels are highest during the summer or driest time of the year. Ground water levels drop during the winter and in many cases very shallow wells may go dry. All of the wells chosen for this study are at depths of 1.5 to 5 meters and held water throughout the sampling period. These depths represent the total depth of the well. Although the water levels do vary based on

Figure 4. Site Conditions at Study Wells.
Picture A. Site Conditions at Study Well E.
Picture B. Study Well A.

A.

B.

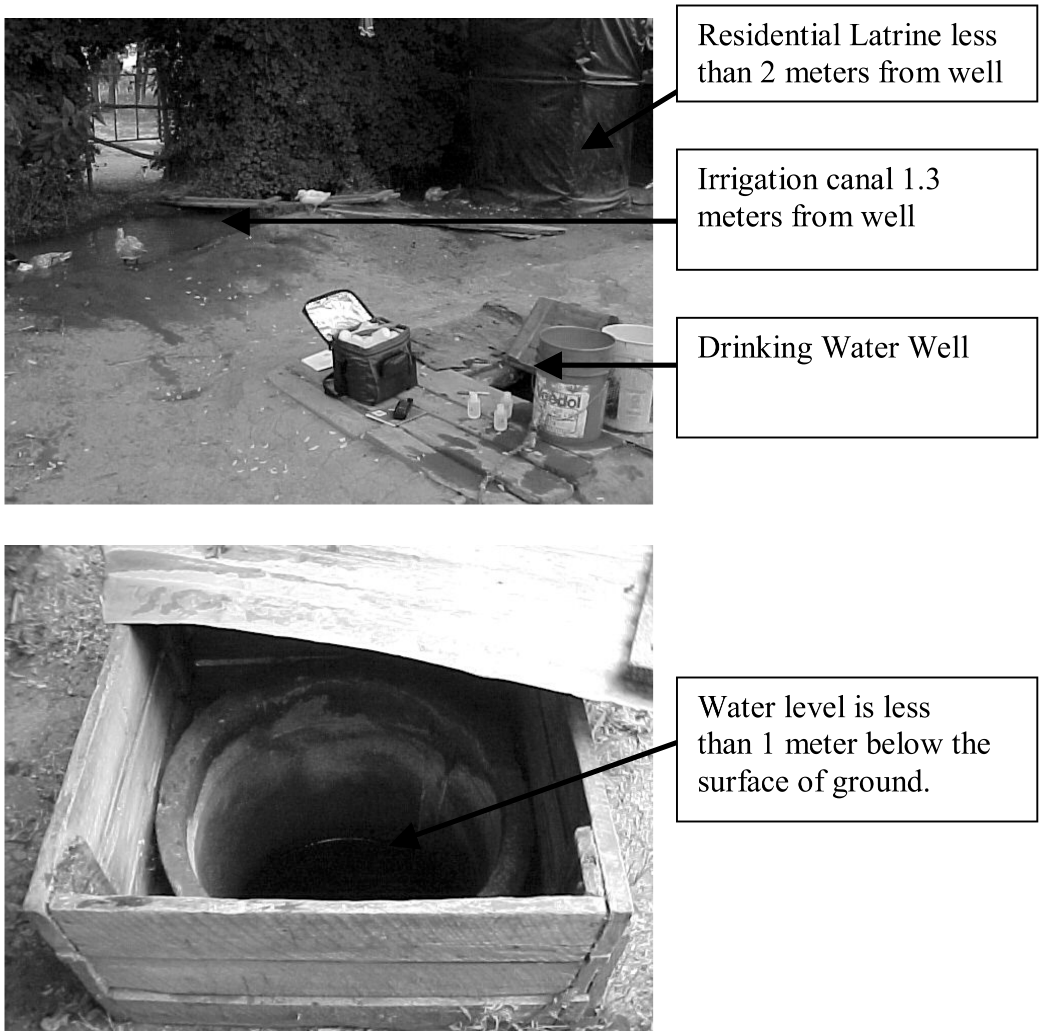
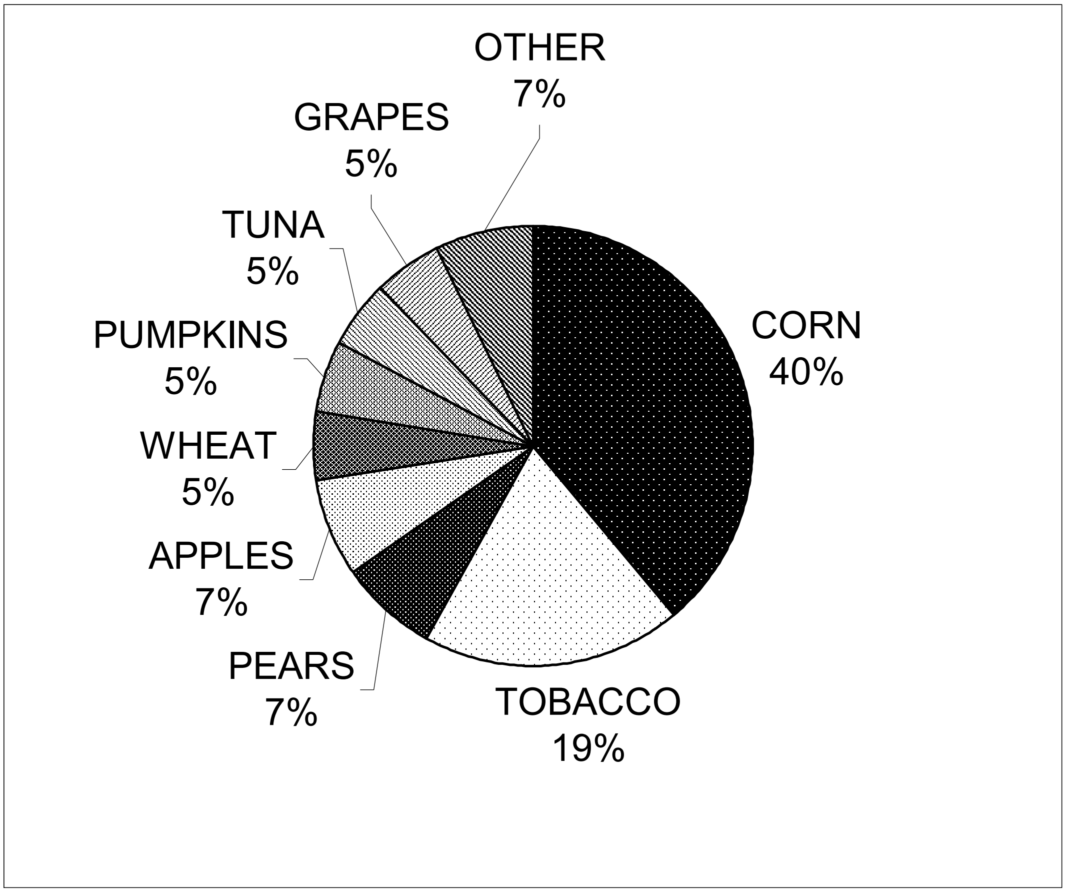


Figure 5. Percentages of Agricultural Land Coverage by Crop Type in the Study Area



seasonal conditions, the average water level is normally 1 meter less than the total depth of the well (Table 5).

Throughout the study region soil conditions are thin and unfertile in areas where fertilizer application is not practiced. The most common soil type is classified as sandy, highly permeable soil with washed stone beneath and the average depth of the soil is 1 meter. In agricultural soils there is very little physical evidence of plant matter or humus with the exception of grazing and livestock fields. In some areas the sandy soil is not present and the washed stone is exposed. In these areas there is no plant matter or physical evidence of an organic component to the soil (humus or duff).

Samples were collected from the study wells on a monthly schedule. All samples were collected in triplicate by a field agronomist working for ChileTobacco/ British American Tobacco. Samples were collected using a dip sampler that was rinsed between sample collections, allowed to air dry, and washed in the study well prior to collecting the sample. Samples were then stored in a freezer until they could be transported back to The University of North Carolina at Wilmington where they were analyzed using a Bran + Luebbe AA3 Auto Analyzer.

Samples were analyzed for NO_3^- (nitrate), NO_2^- (nitrite), NH_4^+(ammonium), PO_4 (phosphate), total nitrogen (TN) and total phosphorus (TP). Organic phosphorus, organic nitrogen, and dissolved inorganic nitrogen were also calculated for each sample. The formulas used for these calculations are listed below.

Dissolved Inorganic Nitrogen (DIN) = $NO_3^- + NO_2^- + NH_4^+$

Organic Nitrogen (DON) = (TN) $-$ DIN

Organic Phosphorus (DOP) = (TP) $-$ PO_4

Table 5. Study Wells and Site Conditions.

WELL	DEPTH OF WELL (METERS)	DISTANCE FROM FIELD (METERS)	DISTANCE FROM IRRIGATION DITCH (METERS)	SURROUNDING CROP TYPE
A	1.5	10.2	3.1	CORN, PEARS
B	1.5	10.2	3.1	CORN, PEARS
C	2	5.1	20	CORN, TOBACCO
D	3	10.3	7.3	TOBACCO
E	2	30.1	1.3	CORN
F	4	20.3	N/A	MIXED VEGETABLE CROPS
G	2	30.7	22.3	GRAPES (TABLE)
H	3	4	20.4	CORN, WHEAT
I	2	11.2	2.6	GRAPES (TABLE), PUMPKINS, TUNA
J	5	3	3.1	CORN
K	4	4.1	6.4	CORN, TOBACCO
L	4	5	3.8	APPLES, GRAPES (TABLE)
M	3	15.2	4.2	TOMATOES
N	3	9	6.2	CORN, TOBACCO
O	4	9	7.3	PEARS, APPLES
P	5	20.1	18.4	CORN
Q	2	30	2.3	APPLES

Standard procedures for sample analysis were followed as outlined in the General Operations Manual for the Technicon Auto Analyzer II (Froelich et al., unpublished laboratory manual, 1977). The techniques used to analyze nitrate, nitrite and phosphate concentrations were based on the Technicon Industrial Methods 158-71 and 155-71.

Once an initial analysis of ground water nitrate concentrations was completed three fields were chosen as test sites for the experimental slurry fertilization/ irrigation systems. In theory this system is loosely based on more advanced systems commonly employed in developed nations. In practice it is very inexpensive by comparison to the aforementioned systems. Professionally designed and marketed entry-level systems employed in Iowa's corn-belt and North Carolina's tobacco fields cost the farmer/ landowner in excess of $1,400.00 US per acre. The considerations taken into account during the design process were that the system must be cost effective in regards to the following: it must be inexpensive to build, easy to repair, and it must be portable. The first prototype was put in place and it was designed around existing irrigation pumping equipment (Figure 6, Picture A). This system is very similar to fertigation systems currently in use, but the system differs in that it uses a granular fertilizer combined with regulated pressure/flow conditions instead of a concentrated, liquid stock solution.

The experimental system was employed in fields C, K, and N. In all three of these fields various treatments of fertilizer application and irrigation volumes were tested while field personnel continually monitored crop yield rates. Crops were physically examined for signs of plant stress and nitrogen deficiencies. Fertilizer application rates and irrigation volumes were experimentally reduced until the crop began to show physical signs of stress. At this point it was decided that fertilizer and water reduction rates would not exceed more than 2/3's of the original application rates and flood volumes. Because this was a commercial crop certain realistic yield expectations (RYEs) had to be maintained. Experimentation with application rates on any commercial crop should be closely monitored and adjusted based on a crop's needs, soil chemistry, plant tissue analysis, yield goals, and field experience. Although these factors were not a direct part of this experiment they were constantly monitored by the agronomists working with the researcher and adjustments were made based on their professional recommendations.

In test fields where the experimental irrigation systems were used, there was a concentrated focus on irrigation volumes and fertilizer application rates. In general, 27,150 US gallons are required deliver one gross inch of water per acre of land. Based on the soil type within the study region it was predetermined by field personnel that the soil intake rate, that is the rate at which water infiltrated the soil surface, was in the range of 0.3 to 0.8 inches/ hour with an average of 0.55 inches/ hour (Castillo, 2003).

In addition to employing the experimental system, full-field flood irrigation was replaced with medium volume furrow flooding in fields surrounding wells C and N and low volume drip irrigation in fields surrounding well K. The experimental irrigation system was considered to be the independent variable in this experiment, with the different methods of water delivery making up the various treatments. The fields surrounding sample wells C and N comprise the first part of the experimental group since they were treated with identical, medium volume systems (Figure 6, Picture B). While the fields surrounding well K were treated with low volume, drip irrigation and make up the second part of the experimental group (Figure 6, Picture C). The effects of the independent variable were quantified by monitoring the nitrate concentrations in the sample wells adjacent to these fields.

Figure 6. Irrigation Applications in the Study Area.
Picture A- Typical Irrigation Pumping System
Picture B- Medium-Volume Furrow Flooding
Picture C- Low-volume Drip Irrigation

A.

B.

C.

Great efforts were made to control as many variables as possible, however the real-world approach taken by using actual commercial crops placed some degree of limitation on experimental design. Irrigation volumes, irrigation times, fertilizer application rates, and RYEs were the only factors that could be monitored with certainty throughout the experimental period. The aforementioned conditions were monitored and regulated to minimize the influence of evaporation and transpiration rates in both experimental and control fields.

DATA AND DISCUSSION

All of the nitrogen data collected in this experiment is presented in Appendix A. While phosphate levels were also monitored, phosphate is not considered to be a threat to human health. However, there are implications that phosphate is a threat to ecosystem health, particularly in freshwater ecosystems where it is often the limiting factor for primary production (USEPA). The two nitrogen compounds of most concern are nitrate and nitrite respectively. The human health MCL for nitrate nitrogen is set at 10 parts per million (ppm) and 2 ppm for nitrite nitrogen (1 ppm = 1 mg/L). Since the human health thresholds for consumption are expressed in ppm and this is the most common measurement found in the reported literature, all data values are expressed in ppm. This unit of measurement differs from most oceanographic nutrient studies where nutrient concentrations are often expressed in micro-molar units.

General Trends in the Data

Though there were other forms of nitrogen measured it was determined that nitrate and nitrite make up the majority of the nitrogen in the wells. Nitrate was determined to account for a mean value of 76.68 percent of the total nitrogen present. Nitrite was determined to represent 13.28 percent of the total nitrogen. Combined, both forms of nitrogen account for an average of 90.06 percent of the total nitrogen present in the ground water samples. Although both nitrate and nitrite were present in all wells in values exceeding the MCL's for each, nitrate concentrations varied greatly between each well and also within a single well during the study period. Mean nitrate concentrations ranged from 8.86 ppm to 296.12 ppm. Nitrite concentrations showed much less variation. Mean nitrite concentrations ranged between 7.46 ppm and 14.56 ppm. In both instances the mean concentration values were calculated by averaging the measured concentrations for each well over the study period (Appendix A).

Analysis of the data shows a general trend in 13 of the 14 wells that made up the control group (Figure 7). In the experimental group, the 3 wells used to monitor the improved irrigation system, this trend was not observed (Figure 8). The trend observed in the control wells is similar to an inverted bell curve and represents irrigation and fertilization practices utilized during the study period. In general, nitrate concentrations are high at the beginning and end of the study period and low during the middle. This trend corresponds to the agricultural time-line for fertilization (both preseason and midseason), irrigation, composting of remaining organics (green manure) and land utilization (Table 2).

The high concentrations of nitrogen present in month 1 (February 2001) represents residual nitrogen from fertilizer application during the growing season. In months 2 to 4 there is a decrease that corresponds to the absence of irrigation and fertilizer application. In months 5 to 7 there is spike in the nitrate concentrations that is difficult to explain but several hypotheses are offered in the next section. Starting around

Figure 7. Sample Well G. General Trend Observed in Wells Used to Monitor Control Fields. Nitrate and Nitrite Concentrations in ppm

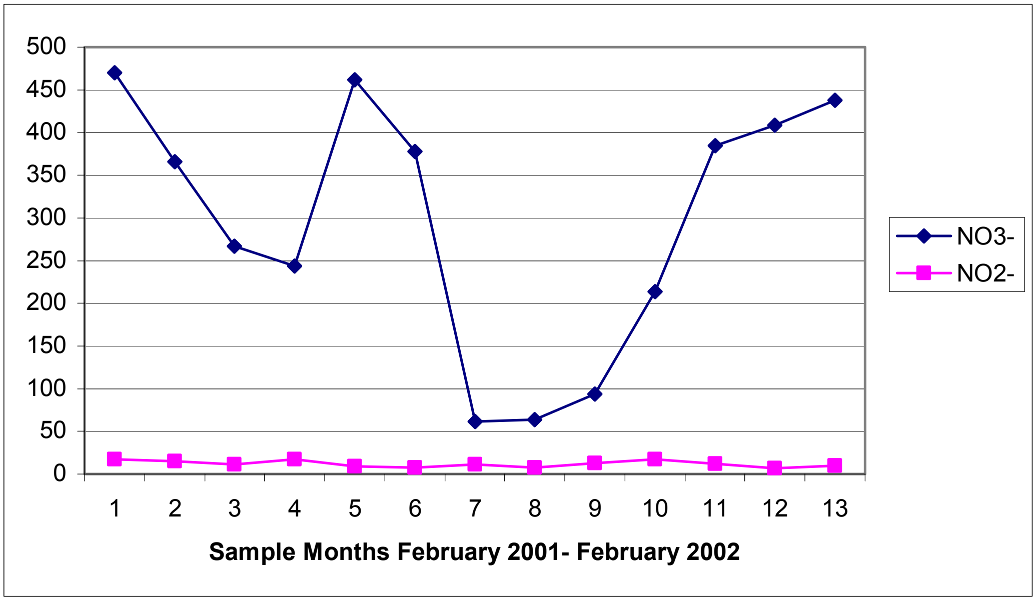
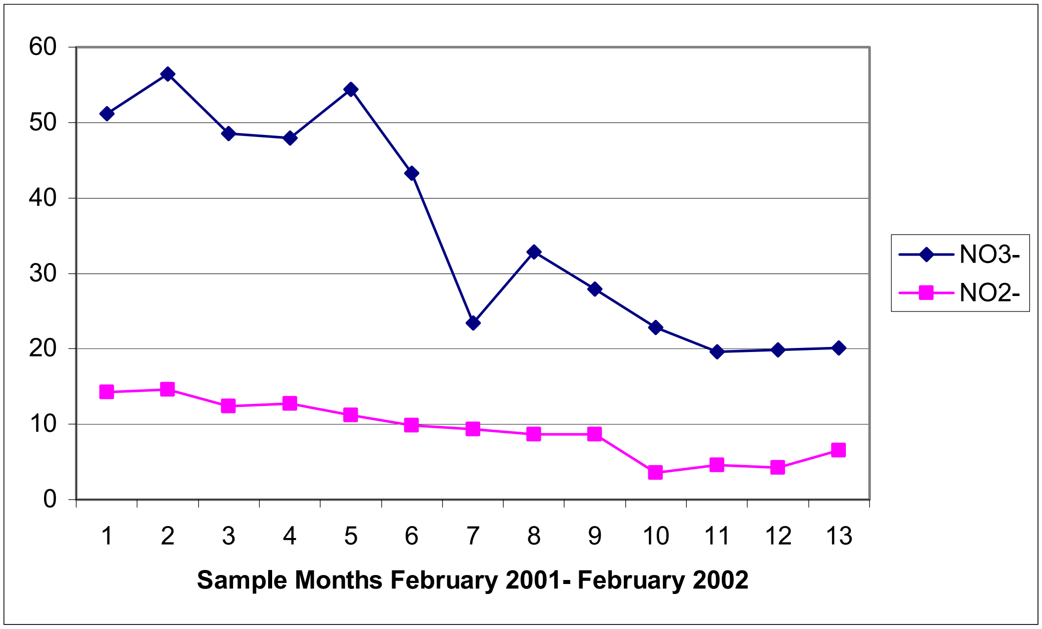


Figure 8. Sample Well C. General Trend Observed in Wells Used to Monitor Experimental Fields. Nitrate and Nitrite Concentrations in ppm



month 9 or 10 there is a gradual increase in nitrate concentrations that corresponds to the preseason application of fertilizer (Table 2).

The positive relationship that exists between the application of fertilizer and nitrate concentrations suggests a dynamic environment within the soil. Less than one month passed between preseason fertilizer application and elevated concentrations of nitrate in the ground water. Since all of the sample wells are deeper than crop root zones, this suggests that the residence time for nitrate within the root zone of the soil is brief. Furthermore, it supports the hypothesis that a lesser amount of fertilizer should be applied and that as much as two-thirds to one-half of the nitrogen fertilizer applied to the land is never utilized by the target crop (Bin-Le et al., 2000). This data also suggests that a decrease in irrigation volumes, particularly during spindling development, would increase the residence time of the fertilizer in the root zone by decreasing the rate of leaching. During this stage of crop development nutrient utilization is often slower than during later stages. This is an excellent time to employ low-volume irrigation techniques.

The Month 5- 7 Concentration Spike

There is no data available to explain the spike in nitrate concentrations between months 5 and 7. Since the water levels in study wells began to decrease during this time of the year, this spike may result from the seasonal lowering of the water table. Although this decrease was noted as a field observation, no data was recorded or is available for analysis.

Although purely speculative, it does appear that there is a loose association between the spike and postseason agricultural activity (Table 2). Once again, no data is present, and this hypothesis is based on observations made by those involved in field collection. The spike appears 6 to 8 weeks after remaining crop matter was plowed into the soil as green manure. The nitrogen tied up in this matter is in a variety of forms, mainly various nitrogen-containing organic compounds. It is plausible that this nitrogen may remain in the soil for a longer period of time before making it into the ground water, hence the 6 to 8 week period between the event and the elevated concentrations (Jimenez et al., 2002).

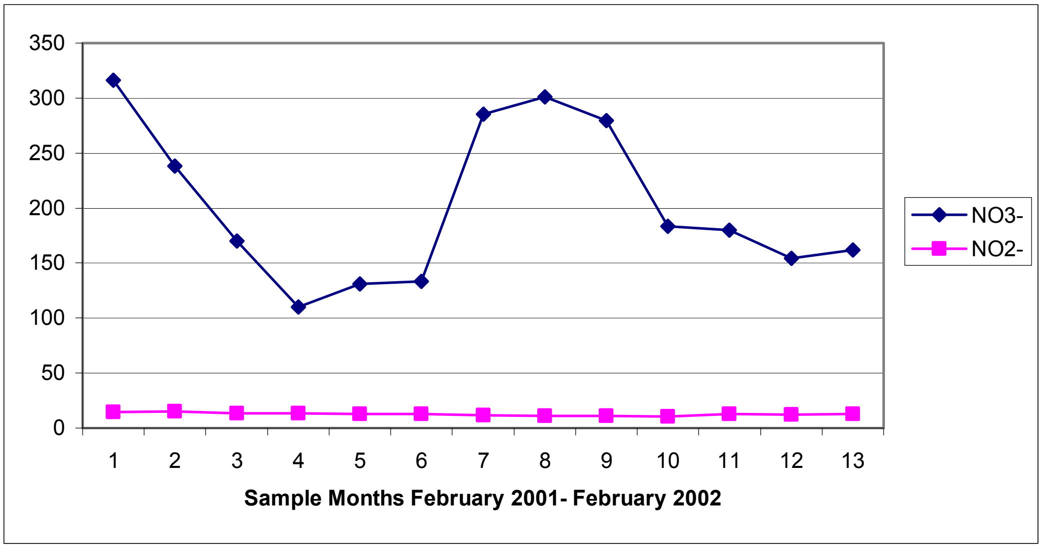
An Exception to the General Trend

Concentrations in sampling well I do not agree with all of the conditions described in the "General Trends in The Data" section of this report (Figure 9). Although the inter-season spike is delayed to month 7 it is still present. The expected increase in concentration starting around month 10 that corresponds to the preseason application of fertilizer in season 2 is not present. Initially this site was considered to be an anomaly, but after an on-site field survey it was determined that this exception was likely due to the fact that the agricultural land area surrounding this well was not utilized in season 2 of this study, thus there was no preseason application of fertilizer. This inactivity may explain the absence of a concentration increase and provides additional support for the positive relationship between elevated nitrogen concentrations and agricultural activity.

Analysis of Wells C, K, N, The Experimental Group

The only situation that allowed for the complete control of fertilizer application and irrigation volumes were in the fields surrounding wells C, K, and N. Rates of application were measured before and after installation of the experimental systems Data from all three wells supports a decrease in nitrate and nitrite concentrations

Figure 9. Sample Well I. Nitrate and Nitrite Concentrations in ppm



(Figure 10). Furthermore, the concentration increase associated with preseason fertilizer application is also not present in these three wells. This trend in the data correlates with use of the experimental system and the resulting decrease in both irrigation volumes and fertilizer application.

In well C there was a decrease of 30.71 ppm of nitrate and 7.69 ppm of nitrite. These values were calculated by comparing concentrations from month 1 (February 2001) to concentrations from month 13 (February 2002). In well K the nitrate concentrations decreased by 181.08 ppm and nitrite concentrations by 10.12 ppm. Finally, in well N nitrate concentrations decreased by 68.41 ppm and nitrite by 8.97 ppm. Using the data from all three wells, the mean decrease in nitrate was calculated at 76 percent and 57 percent for nitrite. The decrease in all three wells was substantial; however, both nitrate and nitrite concentrations still exceed the MCL's established by the USEPA (Figures 10 and 11).

In well K the month 13 concentration (32.07 ppm) was significantly lower than the concentration during month 1 (213.15 ppm). Since directed (at the base of the stalk), low-volume drip irrigation was employed in this field the data suggests an even greater connection between ground water contamination and the volume of irrigation water applied.

In general, fertilizer application and irrigation volumes were reduced by as much as two-thirds once the system was installed. This reduction was achieved while maintaining crop yield at pre-reduction rates (crop yield data was obtained from agronomists in the field after harvest). In all cases the RYEs were met and even exceeded in the fields using the experimental systems.

Figure 10. Sample Wells C, K, and N. Nitrate Concentrations in ppm.

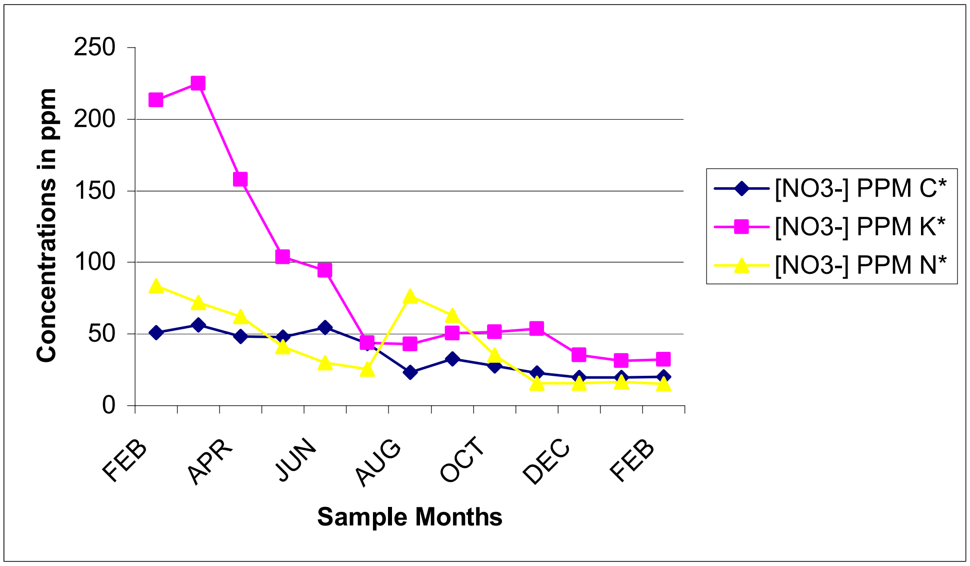
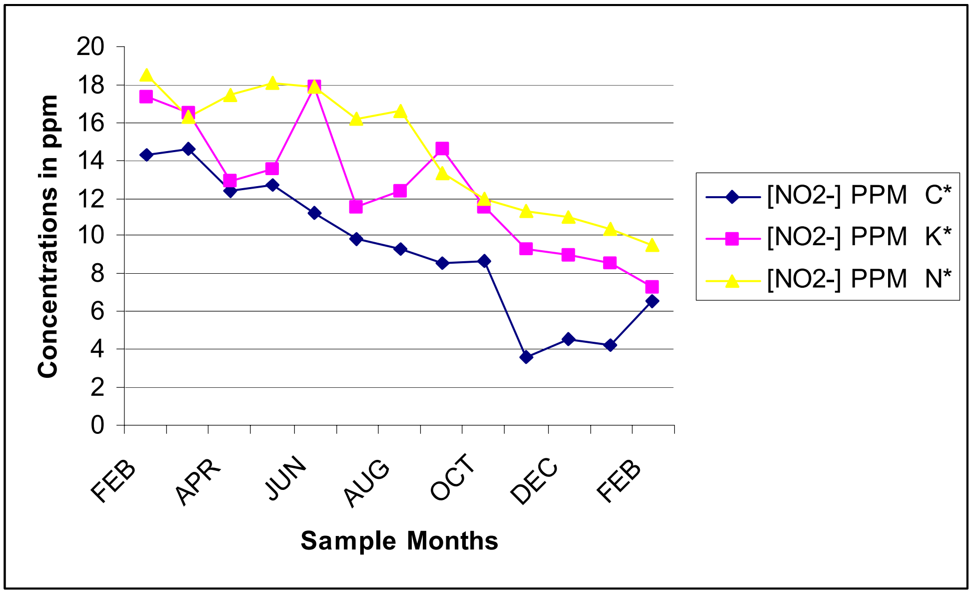


Figure 11. Sample Wells C, K, and N. Nitrite Concentrations in ppm.



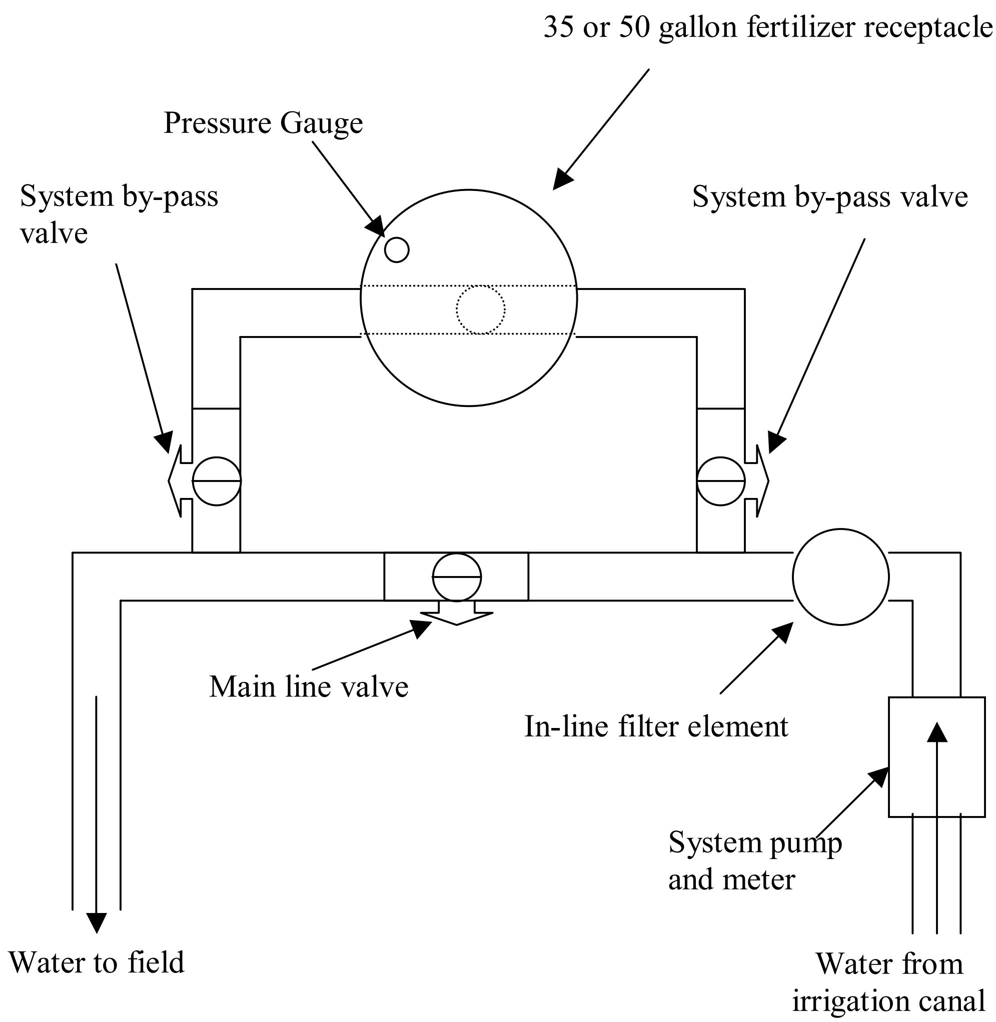
The actual savings of water and fertilizer obviously had to exceed the cost of the system. In this instance a small margin of savings wasn't sufficient and a great deal of effort was put into developing a low-tech system that can be built from non-specific components that are readily available within the agricultural community. This is not to say that this system cannot be employed on a large-scale by multi-national agro-industry. When utilized on a large-scale (e.g. regional or national) the cost to return ratio can be substantial.

The simplicity of the mechanism and the availability of system components make it easy for the system to be duplicated. However, there are several key factors in the system's design that have not been fully disclosed. This is an in-line system that works much like a sand filter on a swimming pool. The exception being that the water is being forced by pressurized flow through a concentrated volume of granular fertilizer. Instead of having a filtering effect, the system creates a fertilizer-rich slurry of irrigation water. When combined with more efficient methods of water delivery, the volume of water and amount of fertilizer applied per acre was reduced substantially (Figure 12).

In the fields surrounding sample well K, irrigation volumes were reduced by over 18,000 gallons per irrigation event and fertilizer was reduced by over 40 pounds. These figures are based on calculated values per acre of crop harvested.

Through experimentation, ratio tables were developed to increase the system's effectiveness. These tables were compiled by including the following considerations: suggested fertilizer application rates (expressed in pounds and kilograms per acre), irrigation water volumes (expressed as a ratio between the water and amount of fertilizer), system flow rates, and system pressure values working together to achieve a

Figure 12. Schematic View of The Experimental Fertilizer-Wash System



desired result. Several major design changes were made in the field, and the end result was a fertilizer slurry/ wash system that proved to be highly effective. In this case the system's effectiveness was measured under the following two parameters: reduced application of fertilizer and irrigation water while maintaining crop yield rates.

The Financial Benefit of Reduced Usage

The difference between rates and volumes with and without the system suggest that a highly efficient system has been developed. When employed properly this system can lead to significant financial savings for the farmer or agribusiness. Using figures obtained from local farmers and agronomists the actual savings per acre was calculated. In calculating this figure the following factors were considered: crop yield per acre and market price of the crop, cost and volume of irrigation water in dollars per cubic feet, and the price of fertilizer per pound and application rates. These factors lead to a direct gross savings of no less than $400 US per acre, per season. This figure does not include the initial cost of materials to construct the system, which should range between $40 - $70 US. It is important to note that once a system is constructed it can be made mobile by mounting on a trailer or transporting in a pickup truck. Since fields are normally irrigated two times per week, this allows a single system to cover a large agricultural area thus compounding the savings with minimal investment.

An example of the annual savings per acre for the average farmer within the study region is explained here. For a farmer producing a Burley variety of tobacco on a single acre a crop yield of 1,780 kilos is a reasonable expectation. With an average market value of $1.40 US dollars/ kilo the farmer could expect to gross just over $2,492 US dollars for every acre farmed. In most circumstances irrigation, fertilization, and related expenses automatically cut the gross profit in half. If this number can be reduced by 66 percent, the farmer will gross an additional $400.00 US /acre. Industry reports show that the average tobacco farmer within the region farms 5.68 acres (Castillo 2003). Simple multiplication shows that the average farmer would save over $2,200 US/ year.

On a regional scale, this savings can benefit those outside of agriculture by being invested in the local economy or used to improve the quality of life for rural families. These savings may also make it possible for more people to receive potable water from deeper, municipal wells. Since these wells are deeper-pulling and have much lower concentrations of nitrogen this could have a direct impact on human health, that is the reduction in ailments associated with excessive nitrogen consumption and the consumption of other agrochemical pollutants.

On a large scale, agribusinesses can roughly estimate a reduction in their seasonal fertilizer and irrigation budgets by as much as two-thirds. Using figures from a multinational agribusiness within the region an annual savings of $2.9 million US was calculated for their continental operations (SA). This figure was calculated by multiplying the number of tobacco producing acres (7,413) by the projected savings of $400 US/ acre. If this system were to be utilized in this company's global operations the savings would increase exponentially.

Finally the long-term effects that reducing a known source of pollution would have on regional ecology and human health is beyond financial quantification.

SUMMARY AND CONCLUSIONS

Concentrations of nitrate and nitrite were well above the human health limits for all of the wells sampled in this study. This data suggests a high level of ground water pollution from nitrogen fertilizers. It is important to consider that the high concentrations of nutrient pollution due to a variety of biogeochemical site conditions may also indicated a high level of other pollutants present in the water (Boyd 2001); (Giebnik, 2003). These pollutants may include but are not limited to fungicides, herbicides, and pesticides (Green et al. 1994). The concentrations of nitrogen discovered in this study suggest that humans should not consume this water and that a serious problem of contamination exists within the region.

It was also determined that soil type, irrigation volumes, and fertilizer application rates do have a direct impact on ground water chemistry. Nitrogen fixing bacteria may play a greater role in the local cycle but their role is difficult to determine and may be overshadowed by the volume of fixed nitrogen applied to the soil.

Considering the results obtained from preliminary field trials of the experimental irrigation system it is highly suggested that this system be considered for large-scale deployment within the region. Efforts to reduce the future application of fertilizer and irrigation water should be considered a priority in all agricultural areas. The data collected in this study further supports the idea that it is less expensive to prevent a contamination event than it is to remediate one.

This system does require additional testing under more controlled conditions. A two-year study would allow better analysis of pre and post seasonal changes in nutrient concentrations. In addition to a lengthened study, more time should be spent in the field in an effort to better understand local soil conditions, ground water hydrology, and agricultural practices. Although some of this information may be available from secondary sources, it has been very difficult to locate. Firsthand experience has proven that there is no substitute for time in the field when a general lack of published material exists for the region. A project involving a greater number of wells and covering a larger range would be more representative of the Central Valley. Furthermore, laboratory testing within the country would solve a number of logistical problems. Finally, the employment of the experimental system and methods on other major crops would provide additional understanding of the systems effectiveness and agrochemical cycles in the region.

Simply put, a reduction in fertilizer and water usage would have global effects in the lithosphere, the hydrosphere, and the atmosphere. A reduction in fertilizer application could lead to a reduction in the amount of nitrogen synthetically fixed. The implications of such an event are too numerous to mention in this summary. If nitrogen fertilizer usage could be reduced by one-half, the world would see a decrease in anthropogenic nitrogen of at least 40 teragrams per year (Table 1.) Simply utilizing fertilizer more efficiently would reduce the gap between anthropogenic nitrogen fixation and natural nitrogen fixation. The consequences of this action would be evident on a global level and trickle down to individual members of a population within a specific ecosystem. A general improvement in ecological and human health could result. This might include an improvement in air and water quality, an increase in floral and aquatic biodiversity, and a reduction in public health spending.

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MAPS AND HISTORICAL DOCUMENTS

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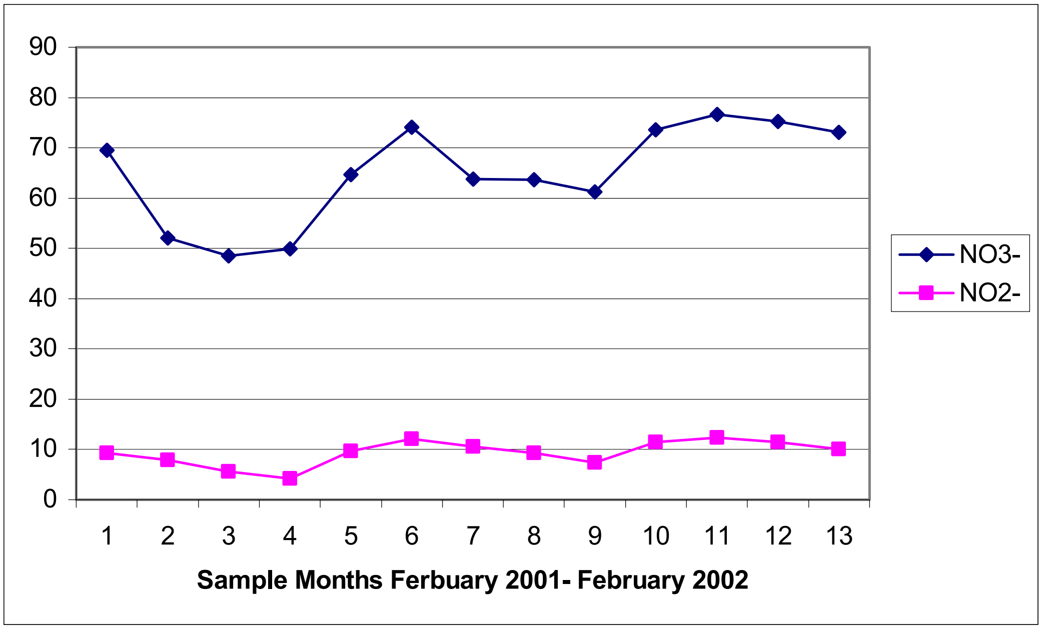
Municipalidad de Nancuaga Archive 2002. Used to determine population statistics for the region, census information available from the municipal government of Colchagua

APPENDIX A. DATA FOR STUDY WELLS A THROUGH Q.

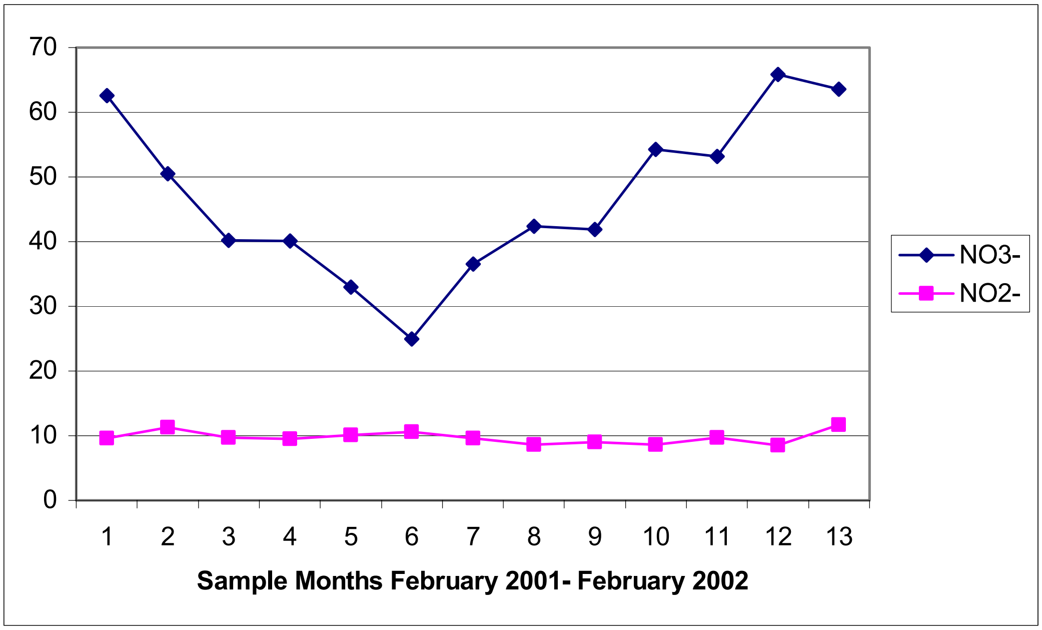
Sample Well A. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well A. Concentrations in ppm

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	69.54	9.31	2	80.85	103.71	22.86
MAR	52.1	7.85	2.3	62.25	111.57	49.32
APR	48.5	5.64	1.7	55.84	104.8	48.96
MAY	49.84	4.21	1.78	55.83	107.03	51.2
JUN	64.64	9.65	1.94	76.23	123.4	47.17
JUL	74.04	12.03	1.96	88.03	159.41	71.38
AUG	63.74	10.52	1.24	75.5	114.7	39.2
SEP	63.67	9.35	1.02	74.04	98.65	24.61
OCT	61.23	7.38	2.38	70.99	108.57	37.58
NOV	73.58	11.4	2.1	87.08	132.2	45.12
DEC	76.58	12.32	0.7	89.6	111.2	21.6
JAN	75.2	11.52	1.94	88.66	97.61	8.95
FEB	73.1	10.02	2.31	85.43	102.4	16.97
MEAN	65.05	9.32	1.79	76.17	113.48	37.30
MEDIAN	64.64	9.65	1.94	76.23	108.57	39.2
RANGE	28	8.11	1.68	32.83	61.8	62.43
STDEV	9.85	2.46	0.51	12.09	16.83	17.39

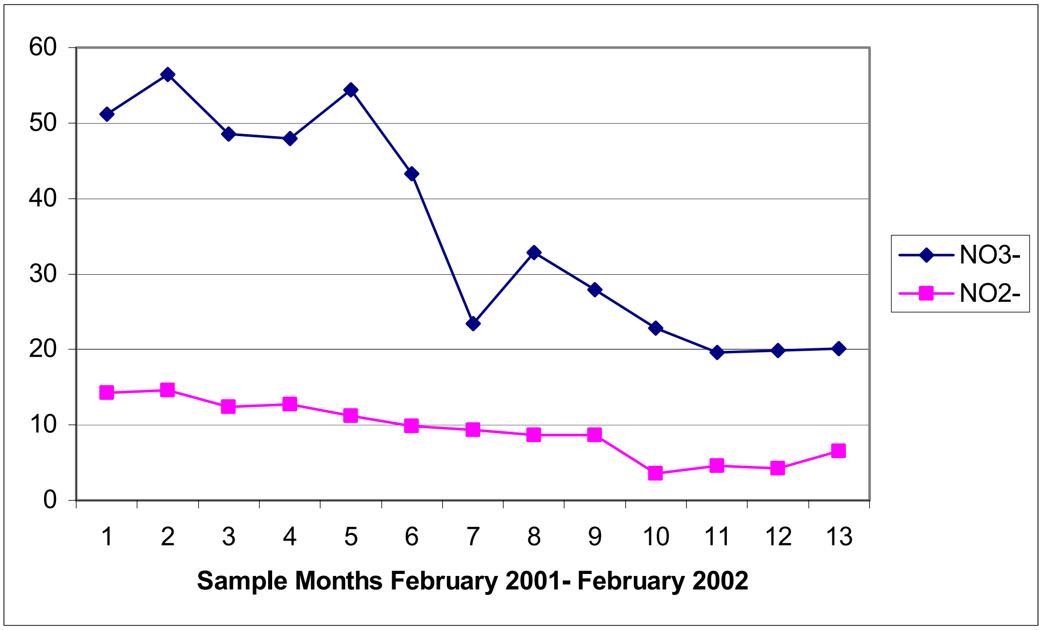
Sample Well B. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well B. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	62.57	9.65	0.89	73.11	92.5	19.39
MAR	50.47	11.24	1.47	63.18	71.2	8.02
APR	40.23	9.68	0.62	50.53	83.1	32.57
MAY	40.12	9.54	2.01	44.68	49.51	4.83
JUN	32.98	10.13	1.57	44.68	47.39	2.71
JUL	24.96	10.57	0.93	36.46	43.15	6.69
AUG	36.58	9.64	1.24	47.46	57.08	9.62
SEP	42.35	8.57	2.03	52.95	63.44	10.49
OCT	41.9	9.03	1.42	52.35	90.24	37.89
NOV	54.27	8.58	1.61	64.46	74.18	9.72
DEC	53.2	9.68	0.97	63.85	70.06	6.21
JAN	65.88	8.55	1.34	75.77	82.13	6.36
FEB	63.54	11.71	1.27	76.52	90.12	13.6
MEAN	46.85	9.74	1.34	57.39	70.32	12.93
MEDIAN	42.35	9.65	1.34	52.95	71.2	9.62
RANGE	41	3.16	1.41	40.06	49.35	35.81
STDEV	12.60	0.98	0.42	13.00	17.12	10.80

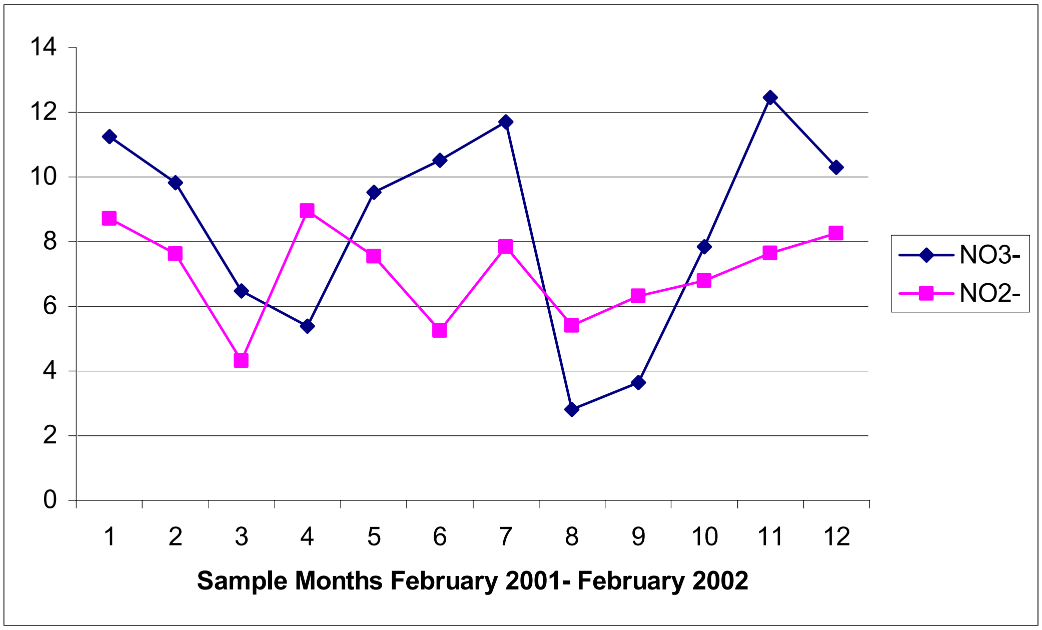
Sample Well C. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well C. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	51.2	14.26	1.54	67	72.51	5.51
MAR	56.4	14.56	1.24	72.2	80.41	8.21
APR	48.51	12.38	0.99	61.88	68.25	6.37
MAY	47.98	12.71	1.06	61.75	69.71	7.96
JUN	54.41	11.24	1.25	66.9	79.08	12.18
JUL	43.31	9.87	2.04	55.22	63.24	8.02
AUG	23.45	9.35	3.11	35.91	41.02	5.11
SEP	32.83	8.62	1.47	42.92	47.93	5.01
OCT	27.9	8.64	1.43	37.97	51.07	13.1
NOV	22.84	3.57	1.22	27.63	43.51	15.88
DEC	19.61	4.59	0.97	25.17	36.34	11.17
JAN	19.87	4.23	1.14	25.24	29.97	4.73
FEB	20.13	6.57	1.83	28.53	37.25	8.72
MEAN	36.03	9.28	1.48	46.79	55.41	8.61
MEDIAN	32.83	9.35	1.25	42.92	51.07	8.02
RANGE	37	10.23	2.14	47.03	50.44	11.15
STDEV	14.51	3.73	0.58	17.85	17.49	3.51

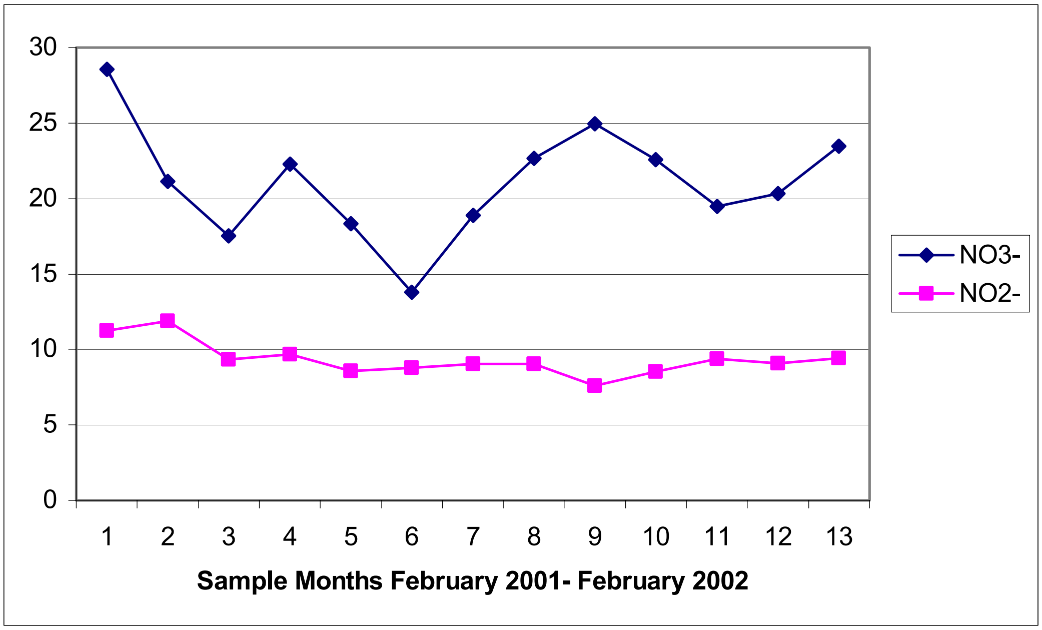
Sample Well D. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well D. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	11.24	8.72	1.28	21.24	28.14	6.9
MAR	9.83	7.63	1.66	19.12	27.33	8.21
APR	6.47	4.31	1.06	11.84	14.27	2.43
MAY	5.38	8.95	1.71	16.04	21.03	4.99
JUN	9.52	7.54	1.35	18.41	20.49	2.08
JUL	10.52	5.24	1.48	17.24	23.06	5.82
AUG	11.7	7.84	1.64	21.18	27.48	6.3
SEP	2.82	5.41	1.28	9.51	13.37	3.86
OCT	3.65	6.32	2.67	12.64	16.08	3.44
NOV	7.84	6.8	2.19	16.83	22.55	5.72
DEC	12.46	7.65	2.03	22.14	26.73	4.59
JAN	10.3	8.25	1.07	19.62	27.4	7.78
FEB	13.4	12.35	1.41	27.16	31.25	4.09
MEAN	8.86	7.46	1.48	17.92	23.01	5.09
MEDIAN	9.83	7.63	1.48	18.41	23.06	4.99
RANGE	10	8.04	1.61	17.65	17.88	6.13
STDEV	3.37	2.03	0.46	4.74	5.73	1.92

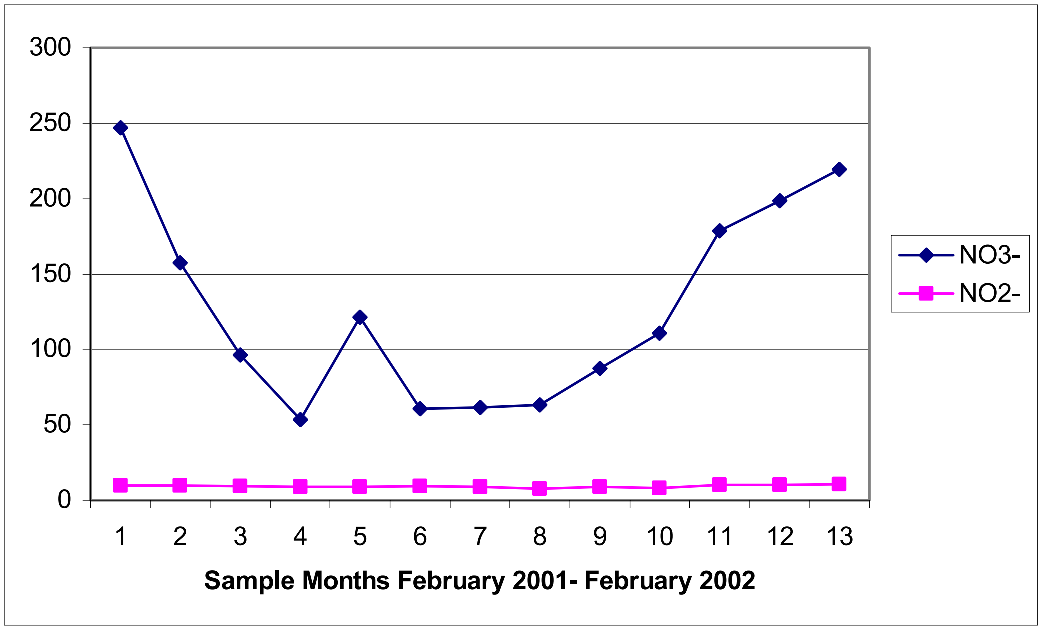
Sample Well E. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well E. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N -N Mineral
FEB	28.54	11.25	1.47	41.26	48.15	6.89
MAR	21.13	11.9	1.24	34.27	39.07	4.8
APR	17.54	9.34	1.68	28.56	33.35	4.79
MAY	22.27	9.68	1.22	33.17	37.01	3.84
JUN	18.32	8.57	1.69	28.58	32.63	4.05
JUL	13.78	8.78	1.49	24.05	28.59	4.54
AUG	18.9	9.02	1.9	29.82	33.77	3.95
SEP	22.68	9.04	1.34	33.06	36.52	3.46
OCT	24.97	7.61	1.77	34.35	38.71	4.36
NOV	22.58	8.52	1.38	32.48	38.66	6.18
DEC	19.46	9.38	1.21	30.05	34.29	4.24
JAN	20.34	9.09	1.04	30.47	34.73	4.26
FEB	23.45	9.41	1.06	33.92	37.85	3.93
MEAN	21.07	9.35	1.42	31.84	36.41	4.56
MEDIAN	21.13	9.09	1.38	32.48	36.52	4.26
RANGE	15	4.29	0.65	17.21	19.56	3.05
STDEV	3.69	1.12	0.27	4.08	4.62	0.96

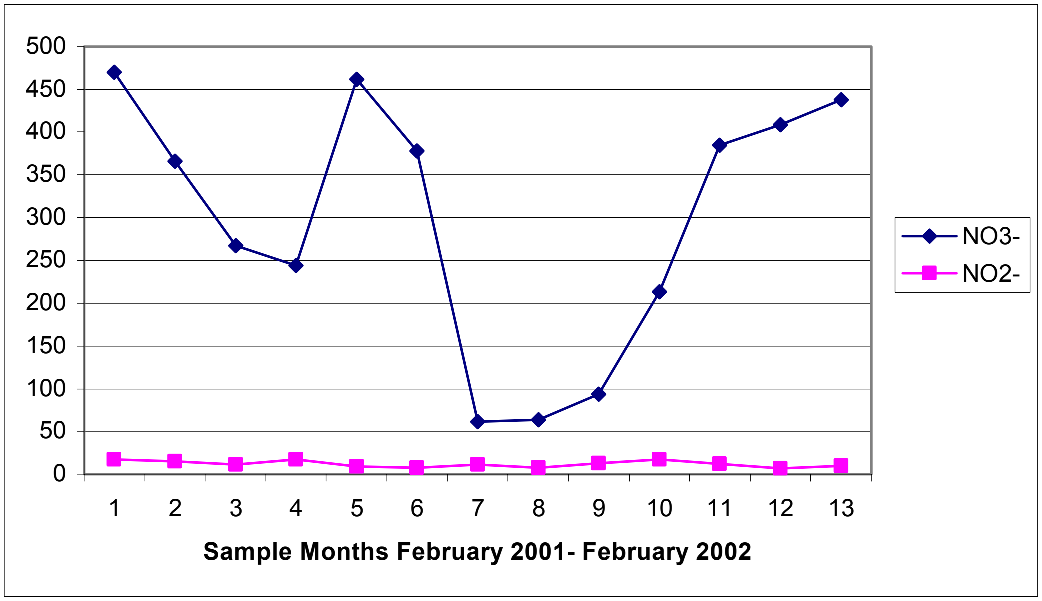
Sample Well F. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well F. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	247.15	9.58	1.54	258.27	263.87	5.6
MAR	157.62	9.68	1.63	168.93	174.59	5.66
APR	96.23	9.47	2.17	107.87	123.8	15.93
MAY	53.26	8.74	1.98	63.98	67.11	3.13
JUN	121.26	8.76	2.31	132.33	140.25	7.92
JUL	60.76	9.54	2.07	72.37	81.63	9.26
AUG	61.51	9.03	2.19	72.73	82.49	9.76
SEP	63.05	7.81	1.94	72.8	79.51	6.71
OCT	87.2	9.06	1.93	98.19	113.07	14.88
NOV	110.57	7.93	1.64	120.14	124	3.86
DEC	178.51	10.21	1.86	190.58	201.3	10.72
JAN	198.64	9.98	1.84	210.46	217.5	7.04
FEB	219.27	10.54	1.75	231.56	242.7	11.14
MEAN	127.31	9.26	1.91	138.48	147.06	8.59
MEDIAN	110.57	9.47	1.93	120.14	124	7.92
RANGE	194	2.73	0.77	194.2	196.76	12.8
STDEV	66.27	0.813	0.23	66.66	66.54	3.90

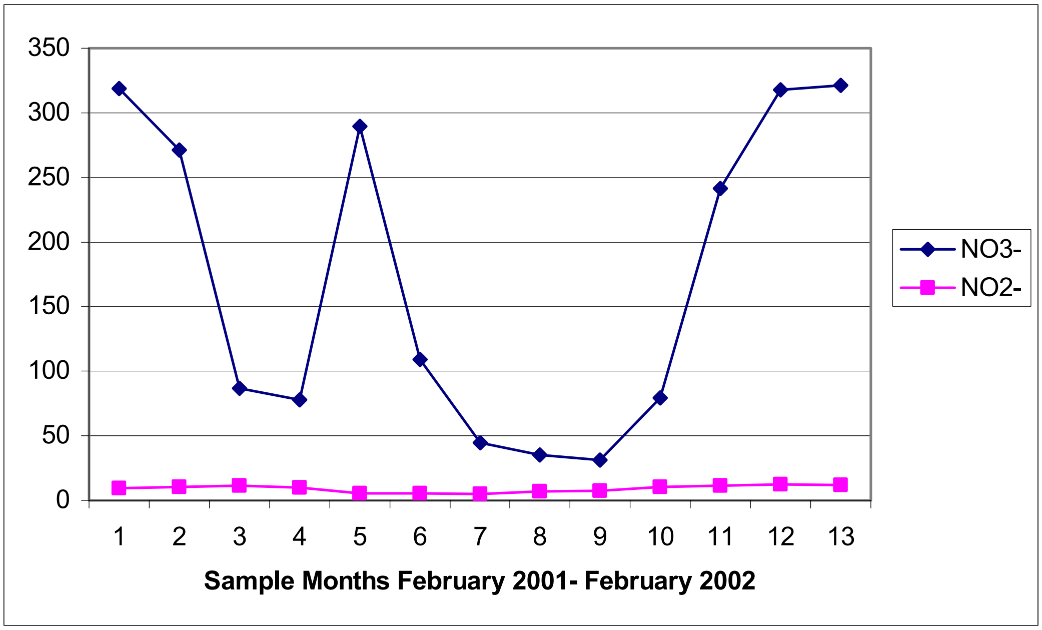
Sample Well G. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well G. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	470.21	16.91	2.54	489.66	491.7	2.04
MAR	365.8	14.83	2.14	382.77	395.21	12.44
APR	267.19	11.41	2.07	280.67	287.35	6.68
MAY	243.67	17.35	1.94	262.96	274.03	11.07
JUN	461.77	8.91	1.33	472.01	478.6	6.59
JUL	377.84	7.35	1.06	386.25	391.24	4.99
AUG	61.25	11.42	1.27	73.94	76.55	2.61
SEP	63.4	7.35	0.99	71.74	79.81	8.07
OCT	93.54	12.54	0.94	107.02	112.39	5.37
NOV	213.57	17.48	1.24	232.29	238.71	6.42
DEC	384.49	11.73	1.67	397.89	403.12	5.13
JAN	408.91	6.57	1.35	416.83	420.09	3.26
FEB	437.94	9.92	1.21	449.07	456.88	7.81
MEAN	296.12	11.83	1.52	309.47	315.82	6.34
MEDIAN	365.8	11.42	1.33	382.77	391.24	6.42
RANGE	407	10.78	1.6	417.92	414.15	10.4
STDEV	150.19	3.85	0.50	150.25	150.18	3.04

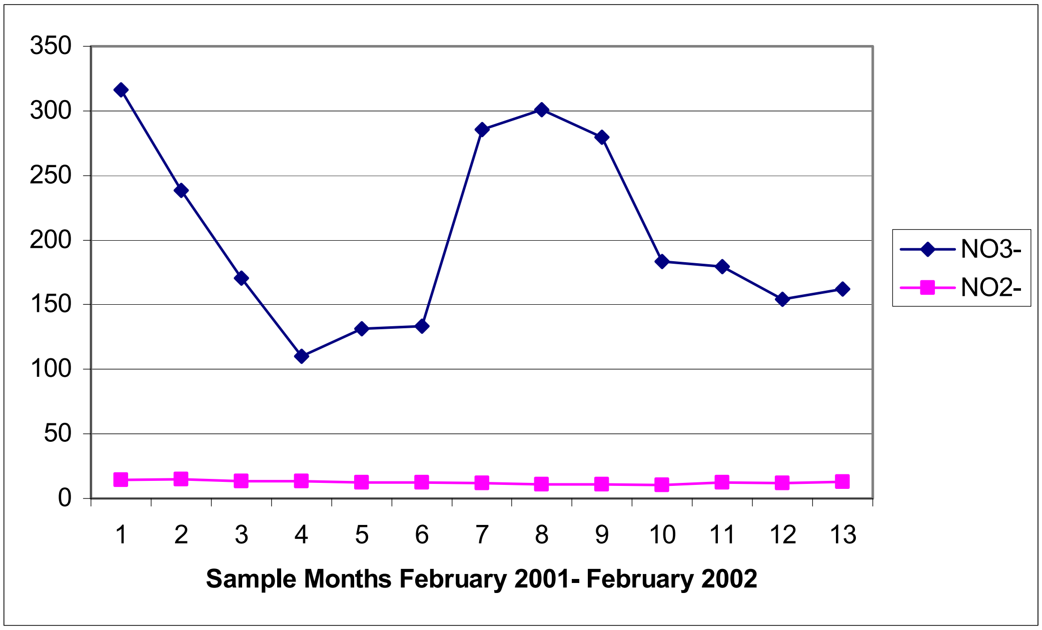
Sample Well H. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well H. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	318.62	9.58	3.64	331.84	336.5	4.66
MAR	271.33	10.2	3.57	285.1	291.03	5.93
APR	86.95	11.47	3.21	101.63	107.59	5.96
MAY	77.63	9.68	2.41	89.72	93.67	3.95
JUN	289.52	5.61	2.84	297.97	301.27	3.3
JUL	109.08	5.37	2.36	116.81	120.35	3.54
AUG	44.42	5.07	1.91	51.4	60.87	9.47
SEP	35.42	7.05	1.97	44.44	47.03	2.59
OCT	31.26	7.62	2.05	40.93	45.68	4.75
NOV	79.21	10.57	2.17	91.95	93.07	1.12
DEC	241.3	11.24	2.22	254.76	257.44	2.68
JAN	317.68	12.3	2.49	332.47	338.55	6.08
FEB	321.45	11.77	2.84	336.06	341.92	5.86
MEAN	171.07	9.04	2.59	182.70	187.31	4.61
MEDIAN	109.08	9.68	2.41	116.81	120.35	4.66
RANGE	290	7.23	1.73	295.13	296.24	8.35
STDEV	121.44	2.58	0.59	122.95	123.12	2.12

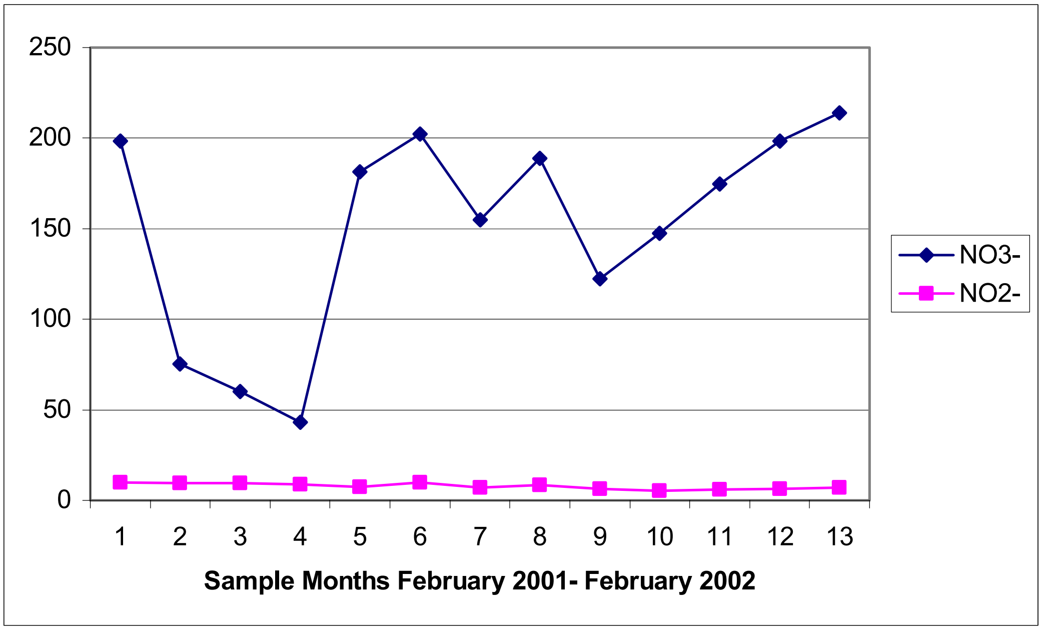
Sample Well I. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well I. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	316.37	14.52	2.31	333.2	338.57	5.37
MAR	238.45	14.97	2.1	255.52	263.12	7.6
APR	170.31	13.57	2.03	185.91	191.02	5.11
MAY	110.27	13.57	1.94	125.78	128.65	2.87
JUN	131.29	12.61	1.66	145.56	148.33	2.77
JUL	133.34	12.64	1.78	147.76	151.07	3.31
AUG	285.62	11.81	1.34	298.77	303.21	4.44
SEP	301.02	11.08	1.38	313.48	314.5	1.02
OCT	279.54	11.02	1.49	292.05	293.4	1.35
NOV	183.27	10.47	1.21	194.95	196.87	1.92
DEC	179.68	12.58	1.05	193.31	194.2	0.89
JAN	154.21	12.07	0.5	166.78	171.84	5.06
FEB	161.87	12.93	1.02	175.82	182.53	6.71
MEAN	203.48	12.60	1.52	217.61	221.33	3.73
MEDIAN	179.68	12.61	1.49	193.31	194.2	3.31
RANGE	206	4.5	1.81	207.42	209.92	6.71
STDEV	71.34	1.34	0.51	71.33	71.38	2.18

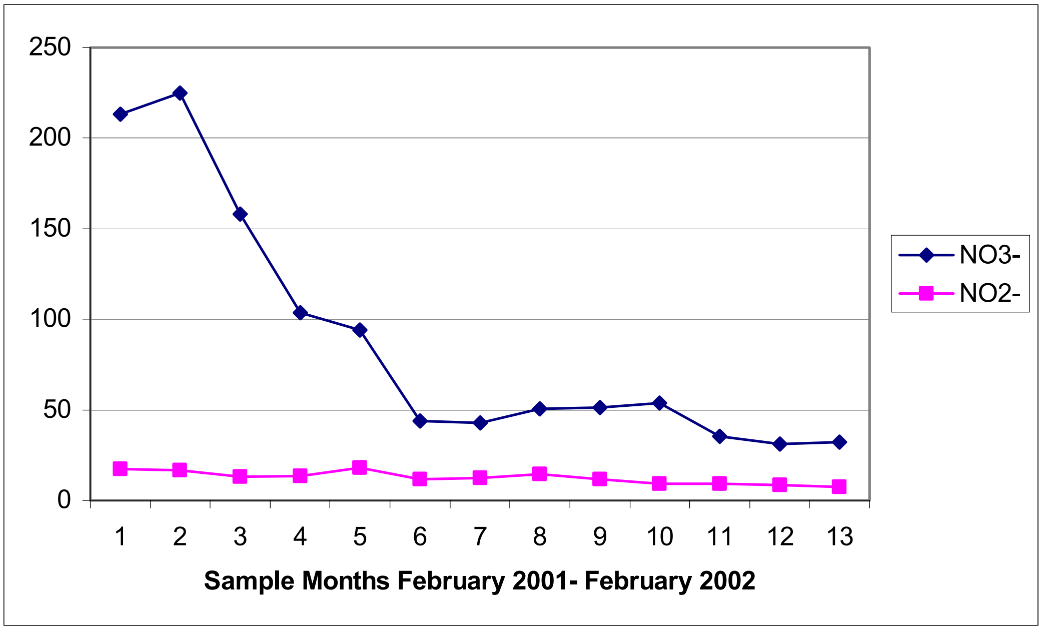
Sample Well J. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well J. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	198.35	9.87	1.33	209.55	211.03	1.48
MAR	75.43	9.5	1.64	86.57	90.07	3.5
APR	60.24	9.54	1.54	71.32	73.58	2.26
MAY	43.09	8.71	1.2	53	54.37	1.37
JUN	181.32	7.58	1.08	189.98	193.51	3.53
JUL	202.16	9.85	1.64	213.65	217.66	4.01
AUG	154.91	7.19	1.97	164.07	170	5.93
SEP	189	8.56	1.62	199.18	201.3	2.12
OCT	122.23	6.24	1.66	130.13	136.4	6.27
NOV	147.48	5.28	1.22	153.98	155.2	1.22
DEC	174.63	6.08	1.07	181.78	183.6	1.82
JAN	198.54	6.31	1.58	206.43	207.19	0.76
FEB	214.07	6.97	1.41	222.45	225.81	3.36
MEAN	150.88	7.82	1.46	160.16	163.05	2.89
MEDIAN	174.63	7.58	1.54	181.78	183.6	2.26
RANGE	171	4.52	0.9	169.45	171.44	5.51
STDEV	58.07	1.60	0.27	57.70	57.70	1.75

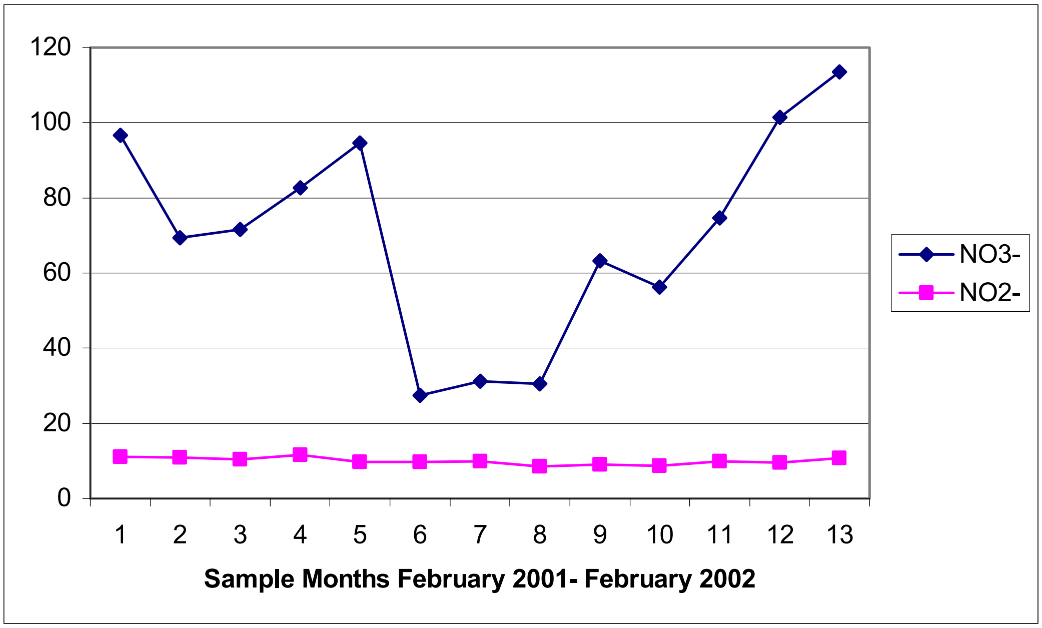
Sample Well K. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well K. Concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	213.15	17.4	1.27	231.82	233.51	1.69
MAR	224.8	16.52	1.41	242.73	247.9	5.17
APR	157.9	12.94	1.77	172.61	180.4	7.79
MAY	103.78	13.5	1.94	119.22	121.67	2.45
JUN	94.164	17.9	0.93	112.994	113.09	0.096
JUL	43.9	11.58	1.64	57.12	62.37	5.25
AUG	42.88	12.37	2.03	57.28	60.25	2.97
SEP	50.65	14.57	2.15	67.37	71.43	4.06
OCT	51.26	11.58	1.67	64.51	68.98	4.47
NOV	53.68	9.35	1.6	64.63	67.16	2.53
DEC	35.4	9.02	1.33	45.75	48.05	2.3
JAN	31.29	8.57	1.07	40.93	41.7	0.77
FEB	32.07	7.32	0.84	40.23	41.65	1.42
MEAN	87.30	12.51	1.51	101.32	104.47	3.15
MEDIAN	51.26	12.37	1.6	64.63	68.98	2.53
RANGE	190	10.58	1.31	202.5	191.86	5.154
STDEV	68.65	1.08	0.41	71.17	71.82	2.13

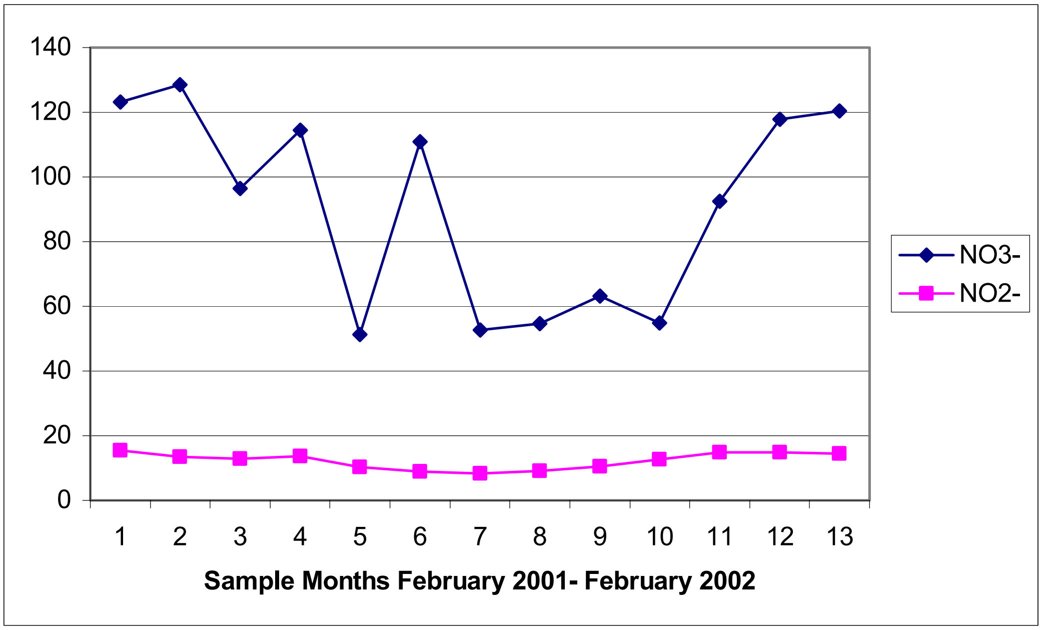
Sample Well L. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well L. concentrations in ppm.

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	96.57	11.04	1.68	109.29	111.34	2.05
MAR	69.32	10.92	2.47	82.71	83.54	0.83
APR	71.54	10.47	2.31	84.32	86.27	1.95
MAY	82.72	11.52	2.74	96.98	98.35	1.37
JUN	94.56	9.68	2.11	106.35	107.58	1.23
JUL	27.39	9.74	2.03	39.16	42.3	3.14
AUG	31.26	9.92	1.94	43.12	44.98	1.86
SEP	30.51	8.5	2.04	41.05	43.06	2.01
OCT	63.2	9.01	1.93	74.14	75.81	1.67
NOV	56.3	8.76	1.87	66.93	68	1.07
DEC	74.59	9.91	1.89	86.39	88.52	2.13
JAN	101.47	9.57	1.72	112.76	113.41	0.65
FEB	113.47	10.81	1.94	126.22	129.07	2.85
MEAN	70.22	9.98	2.05	82.26	84.02	1.75
MEDIAN	71.54	9.91	1.94	84.32	86.27	1.86
RANGE	86	3.02	1.06	85.17	86.77	2.49
STDEV	28.11	0.92	0.30	28.58	28.42	0.73

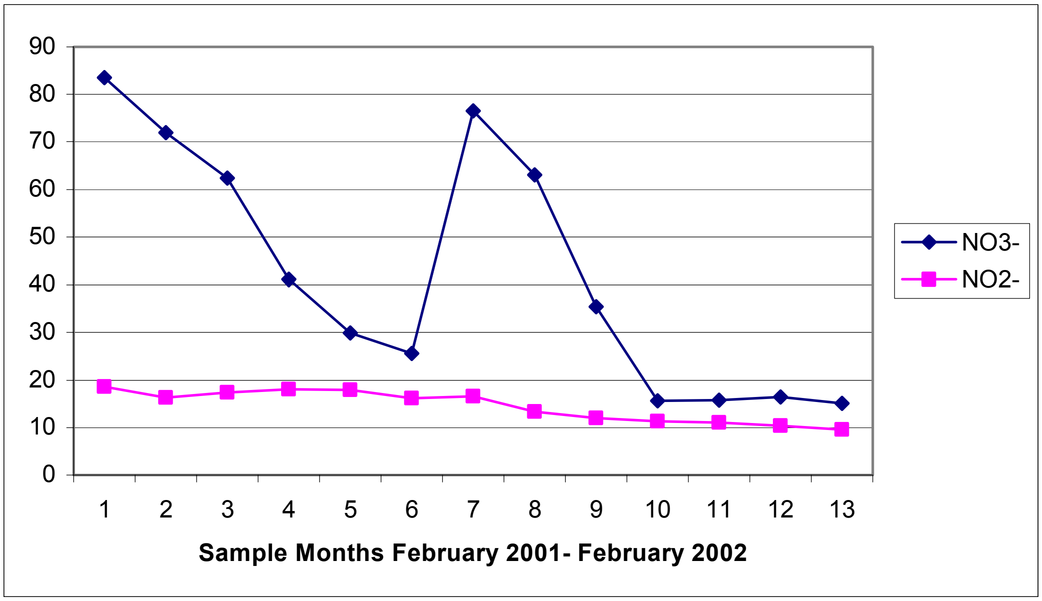
Sample Well M. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well M. Concentrations in ppm

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	123.14	15.48	2.31	140.93	145.63	4.7
MAR	128.52	13.51	2.21	144.24	147.21	2.97
APR	96.34	12.87	2.07	111.28	112.93	1.65
MAY	114.45	13.64	2.38	130.47	133.46	2.99
JUN	51.28	10.24	2.64	64.16	65.97	1.81
JUL	110.89	8.97	2.1	121.96	123.04	1.08
AUG	52.69	8.35	2.79	63.83	65.81	1.98
SEP	54.6	9.04	1.96	65.6	67.42	1.82
OCT	63.2	10.53	1.81	75.54	77.83	2.29
NOV	54.87	12.64	2.08	69.59	70.97	1.38
DEC	92.4	14.77	2.17	109.34	111.25	1.91
JAN	117.85	14.81	1.93	134.59	136.51	1.92
FEB	120.37	14.53	1.64	136.54	137.8	1.26
MEAN	90.82	12.26	2.16	105.24	107.37	2.14
MEDIAN	96.34	12.87	2.1	111.28	112.93	1.91
RANGE	78	7.13	1.15	80.41	79.55	3.62
STDEV	30.89	2.51	0.33	32.57	32.96	0.96

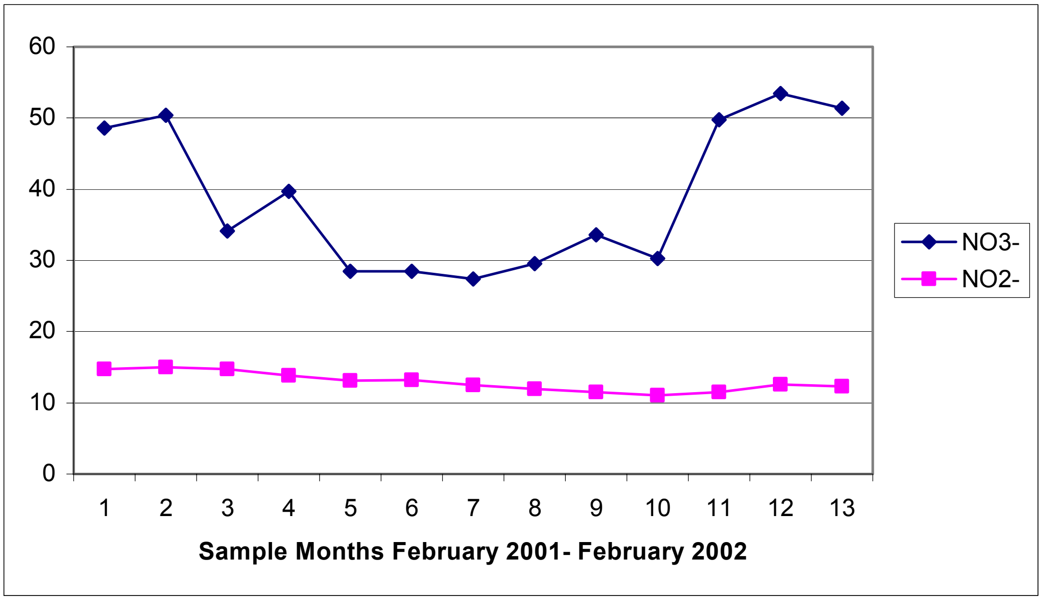
Sample Well N. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well N Concentrations in ppm

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	83.54	18.54	1.57	103.65	109.54	5.89
MAR	71.92	16.34	1.78	90.04	96.03	5.99
APR	62.37	17.41	1.57	81.35	86.47	5.12
MAY	41.03	18.11	1.35	60.49	62.51	2.02
JUN	29.96	17.93	1.98	49.87	53.22	3.35
JUL	25.62	16.22	0.74	42.58	46.37	3.79
AUG	76.47	16.57	2.34	95.38	96.1	0.72
SEP	63.01	13.37	2.54	78.92	81.24	2.32
OCT	35.42	11.96	1.68	49.06	49.87	0.81
NOV	15.61	11.35	0.84	27.8	28.04	0.24
DEC	15.72	11.04	1.57	28.33	31.06	2.73
JAN	16.45	10.42	1.63	28.5	29.83	1.33
FEB	15.13	9.57	1.4	26.1	29.51	3.41
MEAN	42.48	14.53	1.61	58.62	61.52	2.90
MEDIAN	35.42	16.22	1.57	49.87	53.22	2.73
RANGE	69	8.97	1.8	77.5	81.5	5.75
STDEV	25.63	3.30	0.50	28.22	29.18	1.93

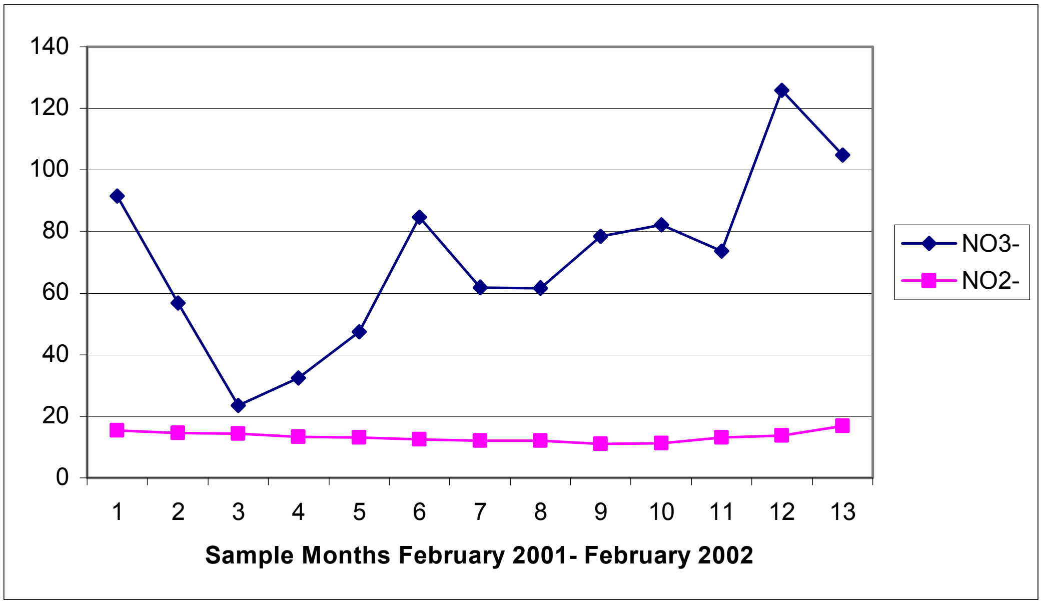
Sample Well O. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well O Concentrations in ppm

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	48.62	14.72	1.47	64.81	67.4	2.59
MAR	50.41	14.96	1.34	66.71	68.21	1.5
APR	34.15	14.77	1.26	50.18	53.79	3.61
MAY	39.7	13.84	1.27	54.81	56.84	2.03
JUN	28.48	13.09	1.67	43.24	47	3.76
JUL	28.43	13.21	1.48	43.12	47.61	4.49
AUG	27.426	12.47	1.63	41.526	43.58	2.05
SEP	29.54	11.94	1.47	42.95	44.31	1.36
OCT	33.61	11.53	0.84	45.98	47.09	1.11
NOV	30.27	11.04	1.24	42.55	48.6	6.35
DEC	49.8	11.51	2.57	63.88	64.97	1.09
JAN	53.47	12.55	2.33	68.35	70.06	1.71
FEB	51.34	12.35	2.1	65.79	68.3	2.51
MEAN	38.87	12.92	1.59	53.38	55.98	2.63
MEDIAN	34.15	12.55	1.47	50.18	53.79	2.05
RANGE	26	3.92	1.73	26.82	26.48	5.24
STDEV	10.31	1.32	0.48	10.95	10.37	1.55

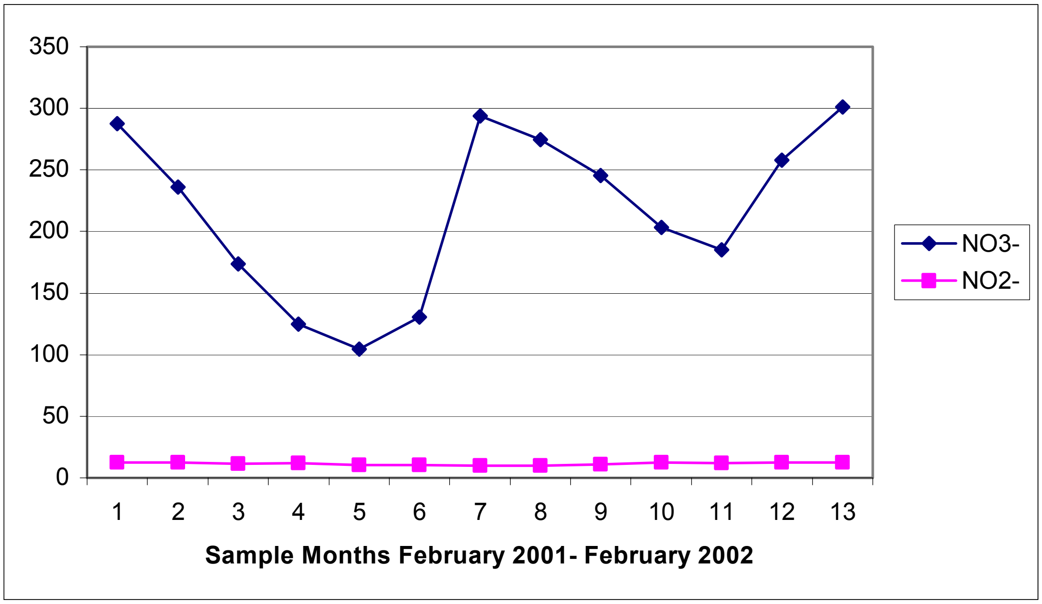
Sample Well P. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well P Concentrations in ppm

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	91.54	15.42	2.54	109.5	111.03	1.53
MAR	56.87	14.61	2.16	73.64	74.51	0.87
APR	23.51	14.35	2.04	39.9	41.22	1.32
MAY	32.54	13.29	2.35	48.18	49.86	1.68
JUN	47.51	13.09	1.97	62.57	64.53	1.96
JUL	84.5	12.57	2.61	99.68	101.02	1.34
AUG	61.88	12.18	1.96	76.02	78.51	2.49
SEP	61.6	12.04	1.85	75.49	77.64	2.15
OCT	78.4	11.08	1.97	91.45	92.31	0.86
NOV	82.1	11.25	1.61	94.96	96.57	1.61
DEC	73.5	13.22	1.57	88.29	89.3	1.01
JAN	125.8	13.84	1.84	141.49	143.58	2.09
FEB	104.7	16.81	1.73	123.27	124.61	1.34
MEAN	71.11	13.37	2.02	86.50	88.05	1.56
MEDIAN	73.5	13.22	1.97	88.29	89.3	1.53
RANGE	81	5.73	0.97	101.59	102.36	1.63
STDEV	28.27	1.64	0.33	28.56	28.57	0.51

Sample Well Q. Nitrate and Nitrite Concentrations in ppm



Combined Nitrogen Data for Well Q Concentrations in ppm

MONTH	NO3-	NO2-	NH3	N Mineral = B+C+D	Total N	N Organic = Total N – N Mineral
FEB	287.4	12.54	2.19	302.13	306.61	4.48
MAR	235.9	12.31	2.36	250.58	254.19	3.61
APR	173.5	11.38	2.07	187.03	192.35	5.32
MAY	125.2	11.94	2.58	139.72	145.61	5.89
JUN	104.5	10.52	2.53	117.602	120.21	2.608
JUL	130.5	10.41	2.19	143.166	144.54	1.374
AUG	293.7	9.65	2.06	305.5	306.81	1.31
SEP	274.5	10.03	2.22	286.81	288	1.19
OCT	245.3	10.84	2.34	258.57	263.47	4.9
NOV	203.1	12.57	2.87	218.58	220.96	2.38
DEC	184.7	11.95	2.19	198.9	200.03	1.13
JAN	257.9	12.61	1.93	272.45	274.8	2.35
FEB	301.2	12.57	2.07	315.88	318.51	2.63
MEAN	216.7	11.49	2.28	230.53	233.55	3.01
MEDIAN	235.9	11.94	2.19	250.58	254.19	2.60
RANGE	197	2.96	0.94	198.27	186.6	4.7
STDEV	68.16	1.07	0.26	68.20	67.94	1.67

Combined Nitrate (NO_3) Data for All Study Wells

	WELL							
MONTH	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
FEB	69.54	62.57	51.2	11.24	28.54	247.15	470.21	318.62
MAR	52.1	50.47	56.4	9.83	21.13	157.62	365.8	271.33
APR	48.5	40.23	48.51	6.47	17.54	96.23	267.19	86.95
MAY	49.84	40.12	47.98	5.38	22.27	53.26	243.67	77.63
JUN	64.64	32.98	54.41	9.52	18.32	121.26	461.77	289.52
JUL	74.04	24.96	43.31	10.52	13.78	60.76	377.84	109.08
AUG	63.74	36.58	23.45	11.7	18.9	61.51	61.25	44.42
SEP	63.67	42.35	32.83	2.82	22.68	63.05	63.4	35.42
OCT	61.23	41.9	27.9	3.65	24.97	87.2	93.54	31.26
NOV	73.58	54.27	22.84	7.84	22.58	110.57	213.57	79.21
DEC	76.58	53.2	19.61	12.46	19.46	178.51	384.49	241.3
JAN	75.2	65.88	19.87	10.3	20.34	198.64	408.91	317.68
FEB	73.1	63.54	20.13	13.4	23.45	219.27	437.94	321.45
MEAN	65.06	46.85	55.95	8.86	21.07	127.31	296.12	171.06
MEDIAN	64.64	42.35	32.83	9.83	21.13	110.57	365.8	109.08
RANGE	28	41	37	10	15	194	407	290
STDEV	9.86	12.61	14.51	3.37	3.70	66.28	150.19	121.44

MONTH	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
FEB	316.37	198.35	213.15	96.57	123.14	83.54	48.62	91.54	287.4
MAR	238.45	75.43	224.8	69.32	128.52	71.92	50.41	56.87	235.91
APR	170.31	60.24	157.9	71.54	96.34	62.37	34.15	23.51	173.58
MAY	110.27	43.09	103.78	82.72	114.45	41.03	39.7	32.54	125.2
JUN	131.29	181.32	94.164	94.56	51.28	29.96	28.48	47.51	104.552
JUL	133.34	202.16	43.9	27.39	110.89	25.62	28.43	84.5	130.566
AUG	285.62	154.91	42.88	31.26	52.69	76.47	27.426	61.88	293.79
SEP	301.02	189	50.65	30.51	54.6	63.01	29.54	61.6	274.56
OCT	279.54	122.23	51.26	63.2	63.2	35.42	33.61	78.4	245.39
NOV	183.27	147.48	53.68	56.3	54.87	15.61	30.27	82.1	203.14
DEC	179.68	174.63	35.4	74.59	92.4	15.72	49.8	73.5	184.76
JAN	154.21	198.54	31.29	101.47	117.85	16.45	53.47	125.81	257.91
FEB	161.87	214.07	32.07	113.47	120.37	15.13	51.34	104.73	301.24
MEAN	203.48	150.88	87.30	70.22	90.82	42.48	38.86	71.11	216.76
MEDIAN	179.68	174.63	51.26	71.54	96.34	35.42	34.15	73.5	235.91
RANGE	206	171	190	86	78	69	26	81	197
STDEV	71.34	58.07	68.65	28.11	30.89	25.63	10.31	28.27	68.16

Combined Nitrite (NO_2) Data for All Study Wells

	WELL							
MONTH	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
FEB	9.31	9.65	14.26	8.72	11.25	9.58	16.91	9.58
MAR	7.85	11.24	14.56	7.63	11.9	9.68	14.83	10.2
APR	5.64	9.68	12.38	4.31	9.34	9.47	11.41	11.47
MAY	4.21	9.54	12.71	8.95	9.68	8.74	17.35	9.68
JUN	9.65	10.13	11.24	7.54	8.57	8.76	8.91	5.61
JUL	12.03	10.57	9.87	5.24	8.78	9.54	7.35	5.37
AUG	10.52	9.64	9.35	7.84	9.02	9.03	11.42	5.07
SEP	9.35	8.57	8.62	5.41	9.04	7.81	7.35	7.05
OCT	7.38	9.03	8.64	6.32	7.61	9.06	12.54	7.62
NOV	11.4	8.58	3.57	6.8	8.52	7.93	17.48	10.57
DEC	12.32	9.68	4.59	7.65	9.38	10.21	11.73	11.24
JAN	11.52	8.55	4.23	8.25	9.09	9.98	6.57	12.3
FEB	10.02	11.71	6.57	12.35	9.41	10.54	9.92	11.77
MEAN	9.32	9.74	9.28	7.46	9.35	9.26	11.83	9.04
MEDIAN	9.65	9.65	9.35	7.63	9.09	9.47	11.42	9.68
RANGE	8.11	3.16	10.23	8.04	4.29	2.73	10.78	7.23
STDEV	2.47	0.99	3.73	2.03	1.12	0.81	3.85	2.58

MONTH	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
FEB	14.52	9.87	17.4	11.04	15.48	18.54	14.72	15.42	12.54
MAR	14.97	9.5	16.52	10.92	13.51	16.34	14.96	14.61	12.31
APR	13.57	9.54	12.94	10.47	12.87	17.41	14.77	14.35	11.38
MAY	13.57	8.71	13.5	11.52	13.64	18.11	13.84	13.29	11.94
JUN	12.61	7.58	17.9	9.68	10.24	17.93	13.09	13.09	10.52
JUL	12.64	9.85	11.58	9.74	8.97	16.22	13.21	12.57	10.41
AUG	11.81	7.19	12.37	9.92	8.35	16.57	12.47	12.18	9.65
SEP	11.08	8.56	14.57	8.5	9.04	13.37	11.94	12.04	10.03
OCT	11.02	6.24	11.58	9.01	10.53	11.96	11.53	11.08	10.84
NOV	10.47	5.28	9.35	8.76	12.64	11.35	11.04	11.25	12.57
DEC	12.58	6.08	9.02	9.91	14.77	11.04	11.51	13.22	11.95
JAN	12.07	6.31	8.57	9.57	14.81	10.42	12.55	13.84	12.61
FEB	12.93	6.97	7.32	10.81	14.53	9.57	12.35	16.81	12.57
MEAN	12.60	7.82	12.51	9.99	12.26	14.56	12.92	13.36	11.48
MEDIAN	12.61	7.58	12.37	9.91	12.87	16.22	12.55	13.22	11.94
RANGE	4.5	4.52	10.58	3.02	7.13	8.97	3.92	5.73	2.96
STDEV	1.34	1.60	1.08	0.92	2.51	3.30	1.32	1.64	1.07